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(54) **PARALLELIZATION AND INSTRUMENTATION IN A PRODUCER GRAPH ORIENTED PROGRAMMING FRAMEWORK**

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CPC ***G06F 9/4428*** (2013.01); ***G06F 9/4436*** (2013.01); ***G06F 11/3404*** (2013.01); ***G06F 11/3419*** (2013.01); ***G06F 11/3495*** (2013.01); *G06F 11/3428* (2013.01); *G06F 2201/865* (2013.01)

(58) **Field of Classification Search**
USPC 717/119
See application file for complete search history.

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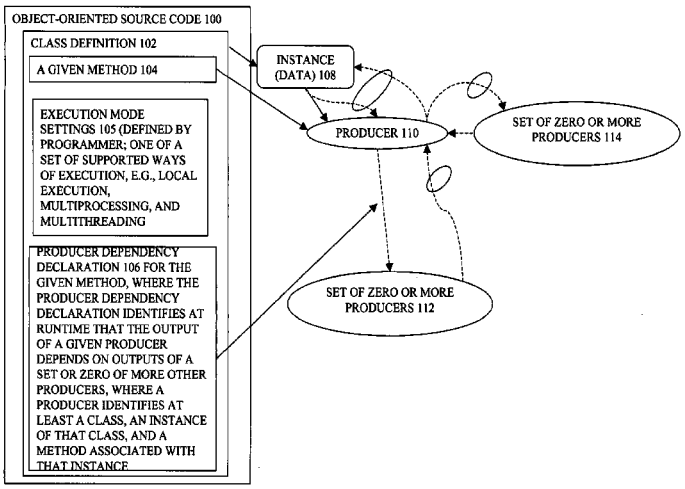
(57) **ABSTRACT**

Embodiments of parallelization and/or instrumentation in a producer graph oriented programming framework have been presented. In one embodiment, a request to run an application program is received, wherein object-oriented source code of the application program includes methods and producer dependency declarations, wherein the producer dependency declaration for a given method identifies a set of zero or more producers with outputs that are an input to the given method, wherein a producer is at least an instance and a method associated with that instance. Further, execution of the application program may be parallelized based on dependency between producers of the application program using the runtime. In some embodiments, the application program is instrumented using the runtime.

22 Claims, 57 Drawing Sheets



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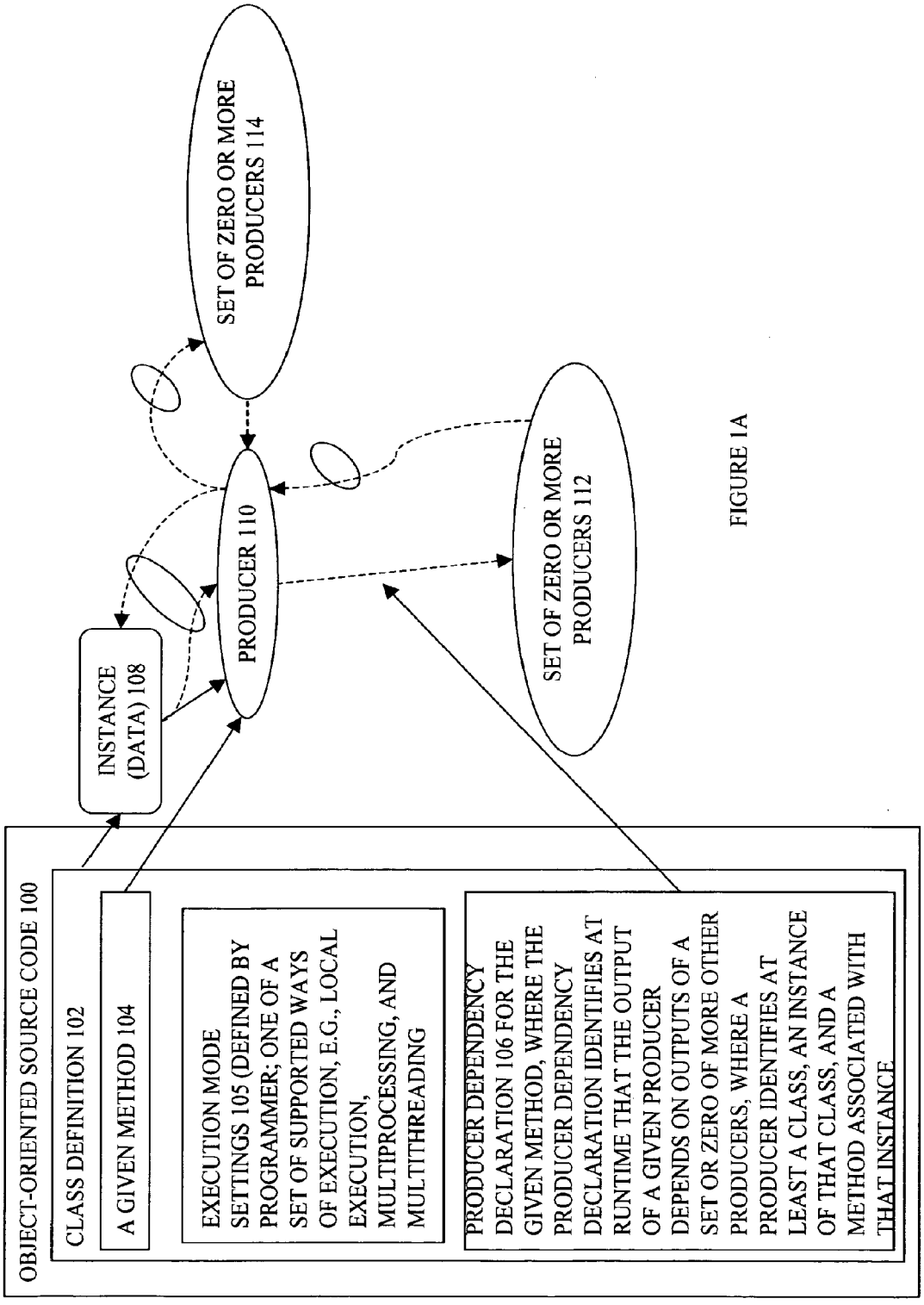
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PRODUCER DEPENDENCY DECLARATION 106 FOR THE GIVEN METHOD, WHERE THE PRODUCER DEPENDENCY DECLARATION IDENTIFIES AT RUNTIME THAT THE OUTPUT OF A GIVEN PRODUCER DEPENDS ON OUTPUTS OF A SET OR ZERO OF MORE OTHER PRODUCERS, WHERE A PRODUCER IDENTIFIES AT LEAST A CLASS, AN INSTANCE OF THAT CLASS, AND A METHOD ASSOCIATED WITH THAT INSTANCE
INSTANCE (DATA) 108
PRODUCER 110
SET OF ZERO OR MORE PRODUCERS 112
SET OF ZERO OR MORE PRODUCERS 114

FIGURE 1A

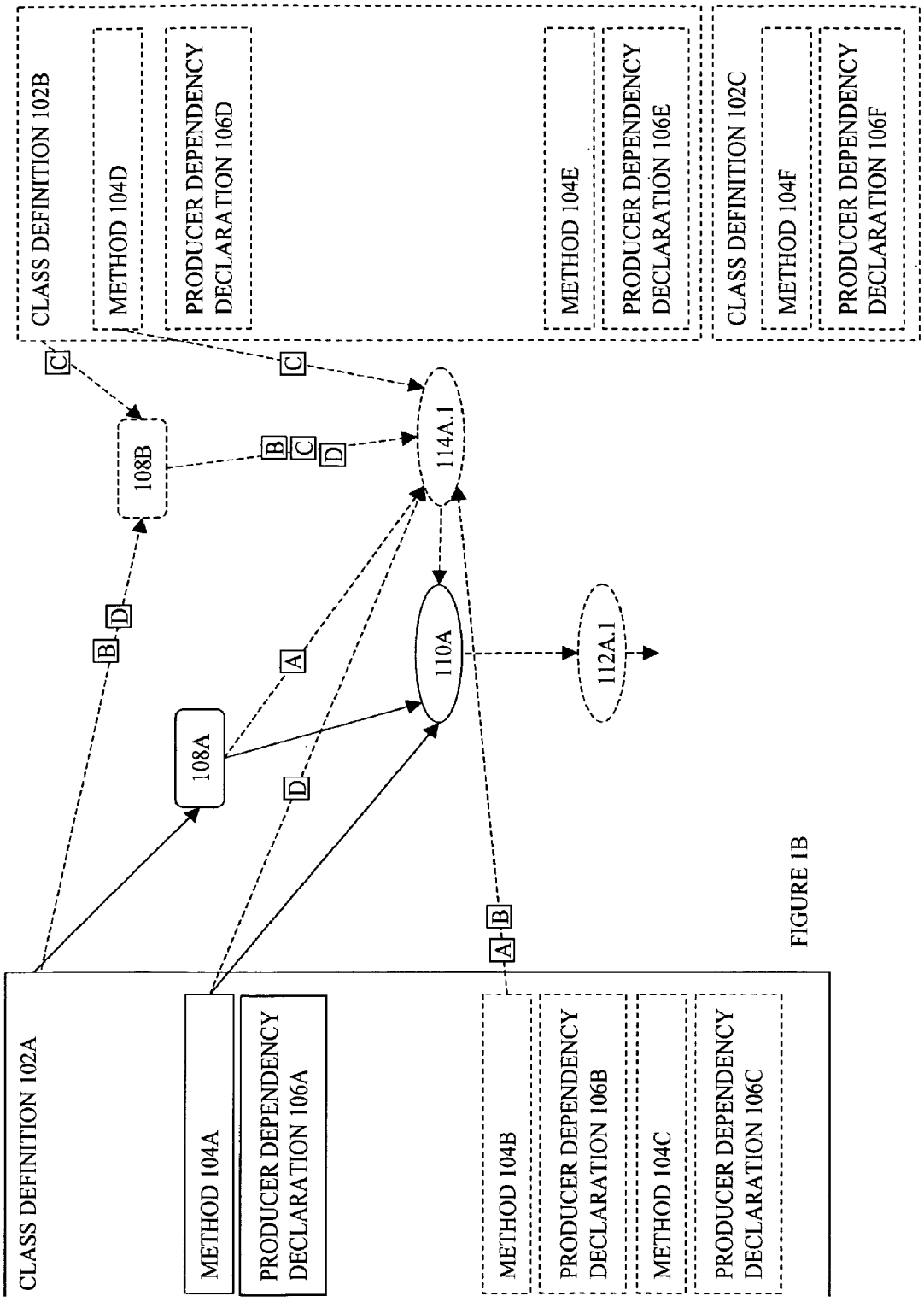

CLASS DEFINITION 102A
METHOD 104A
PRODUCER DEPENDENCY DECLARATION 106A
METHOD 104B
PRODUCER DEPENDENCY DECLARATION 106B
METHOD 104C
PRODUCER DEPENDENCY DECLARATION 106C
CLASS DEFINITION 102B
METHOD 104D
PRODUCER DEPENDENCY DECLARATION 106D
METHOD 104E
PRODUCER DEPENDENCY DECLARATION 106E
CLASS DEFINITION 102C
METHOD 104F
PRODUCER DEPENDENCY DECLARATION 106F
108A
108B
110A
112A.1
114A.1
A
B
C
D

FIGURE 1B

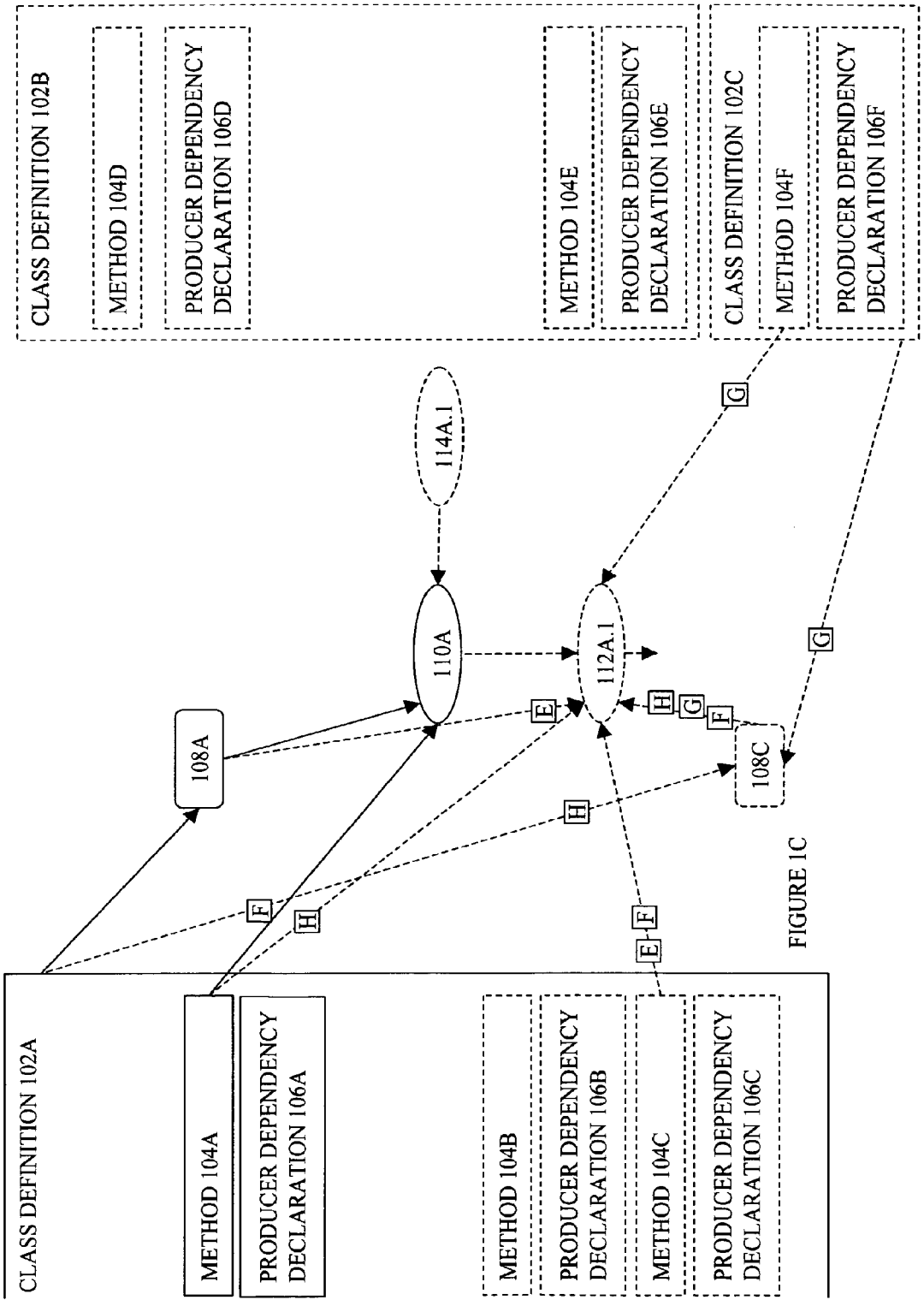

CLASS DEFINITION 102A
METHOD 104A
PRODUCER DEPENDENCY DECLARATION 106A
METHOD 104B
PRODUCER DEPENDENCY DECLARATION 106B
METHOD 104C
PRODUCER DEPENDENCY DECLARATION 106C
CLASS DEFINITION 102B
METHOD 104D
PRODUCER DEPENDENCY DECLARATION 106D
METHOD 104E
PRODUCER DEPENDENCY DECLARATION 106E
CLASS DEFINITION 102C
METHOD 104F
PRODUCER DEPENDENCY DECLARATION 106F
108A
110A
114A.1
112A.1
108C
E
F
G
H

FIGURE 1C

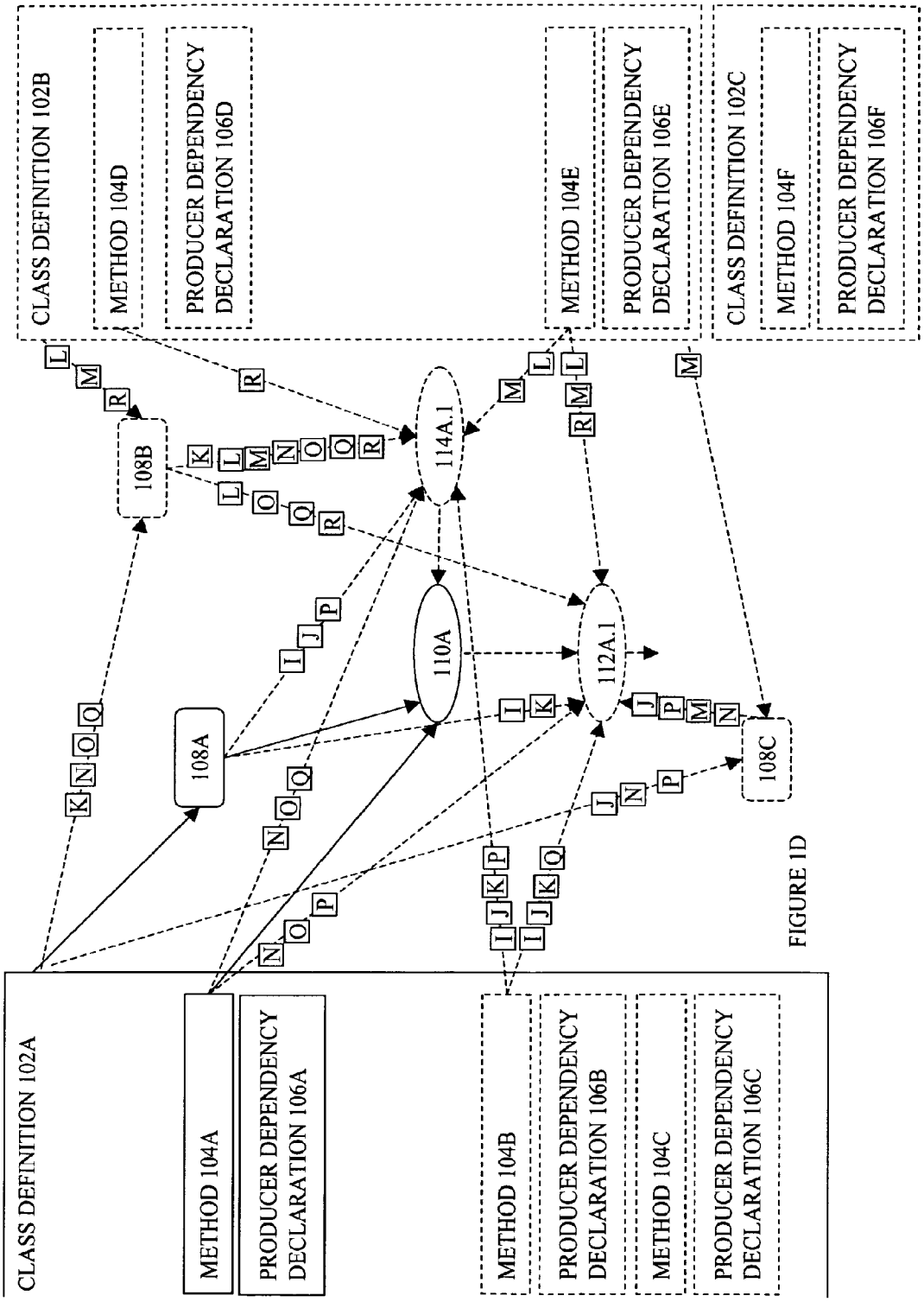

CLASS DEFINITION 102A
METHOD 104A
PRODUCER DEPENDENCY DECLARATION 106A
METHOD 104B
PRODUCER DEPENDENCY DECLARATION 106B
METHOD 104C
PRODUCER DEPENDENCY DECLARATION 106C
CLASS DEFINITION 102B
METHOD 104D
PRODUCER DEPENDENCY DECLARATION 106D
METHOD 104E
PRODUCER DEPENDENCY DECLARATION 106E
CLASS DEFINITION 102C
METHOD 104F
PRODUCER DEPENDENCY DECLARATION 106F
108A
108B
108C
110A
112A.1
114A.1

FIGURE 1D

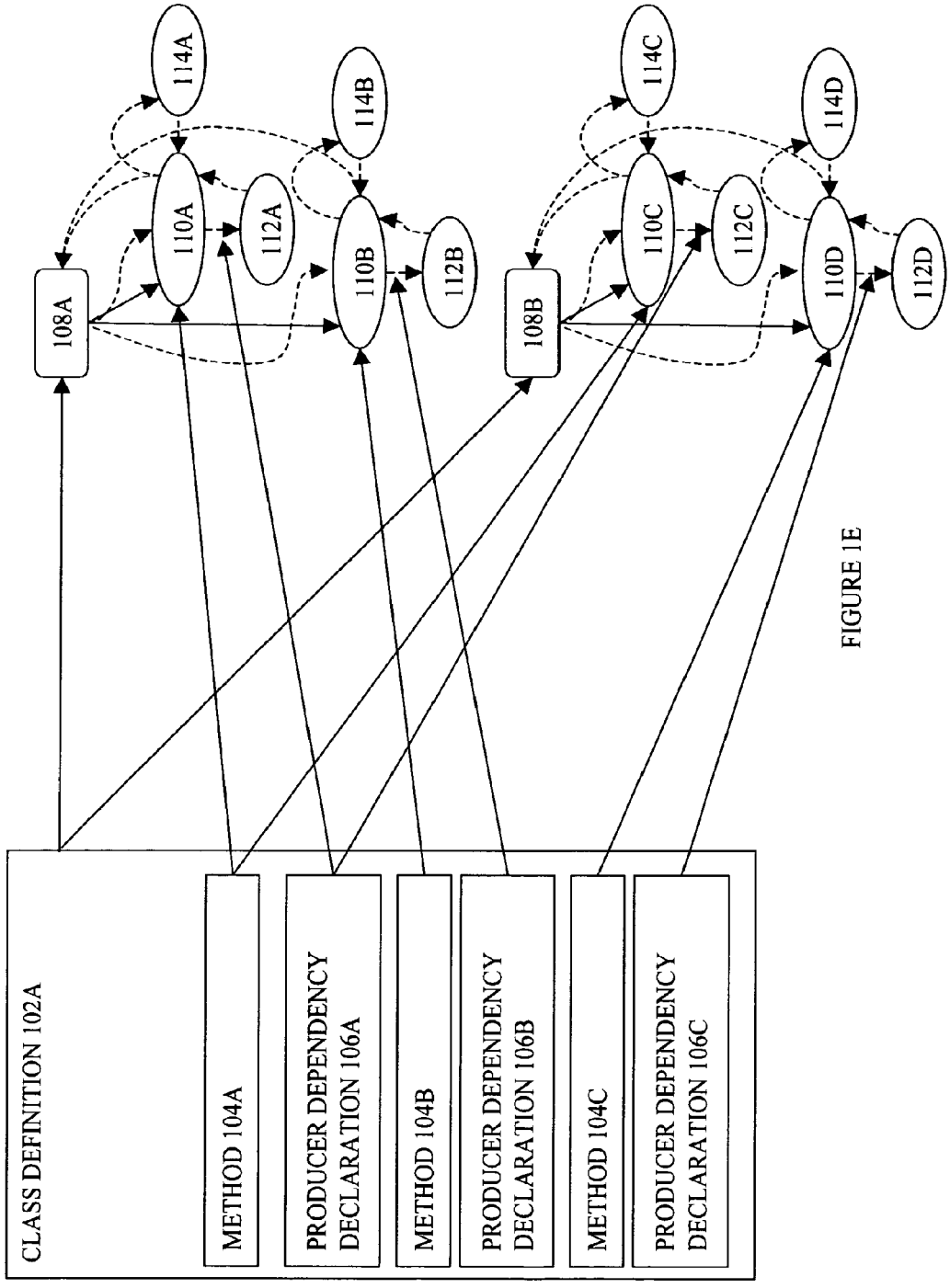

CLASS DEFINITION 102A
METHOD 104A
PRODUCER DEPENDENCY DECLARATION 106A
METHOD 104B
PRODUCER DEPENDENCY DECLARATION 106B
METHOD 104C
PRODUCER DEPENDENCY DECLARATION 106C
108A
108B
110A
110B
110C
110D
112A
112B
112C
112D
114A
114B
114C
114D

FIGURE 1E

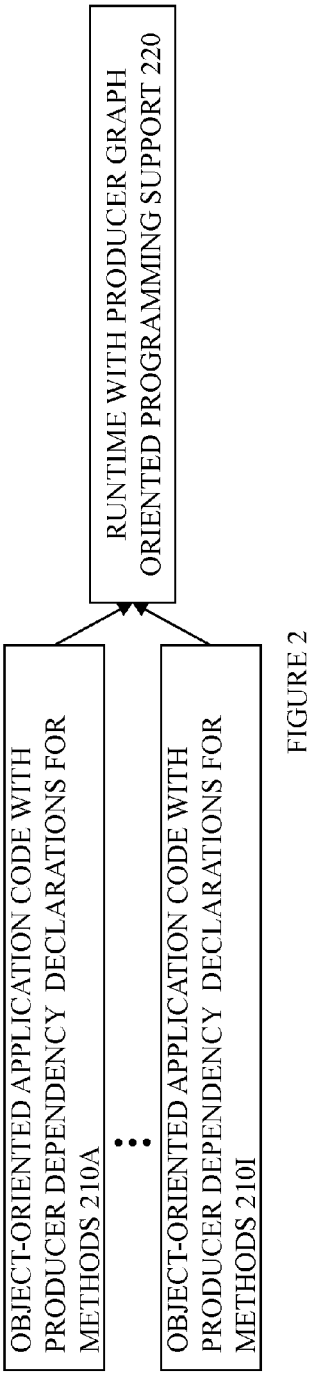


FIGURE 2

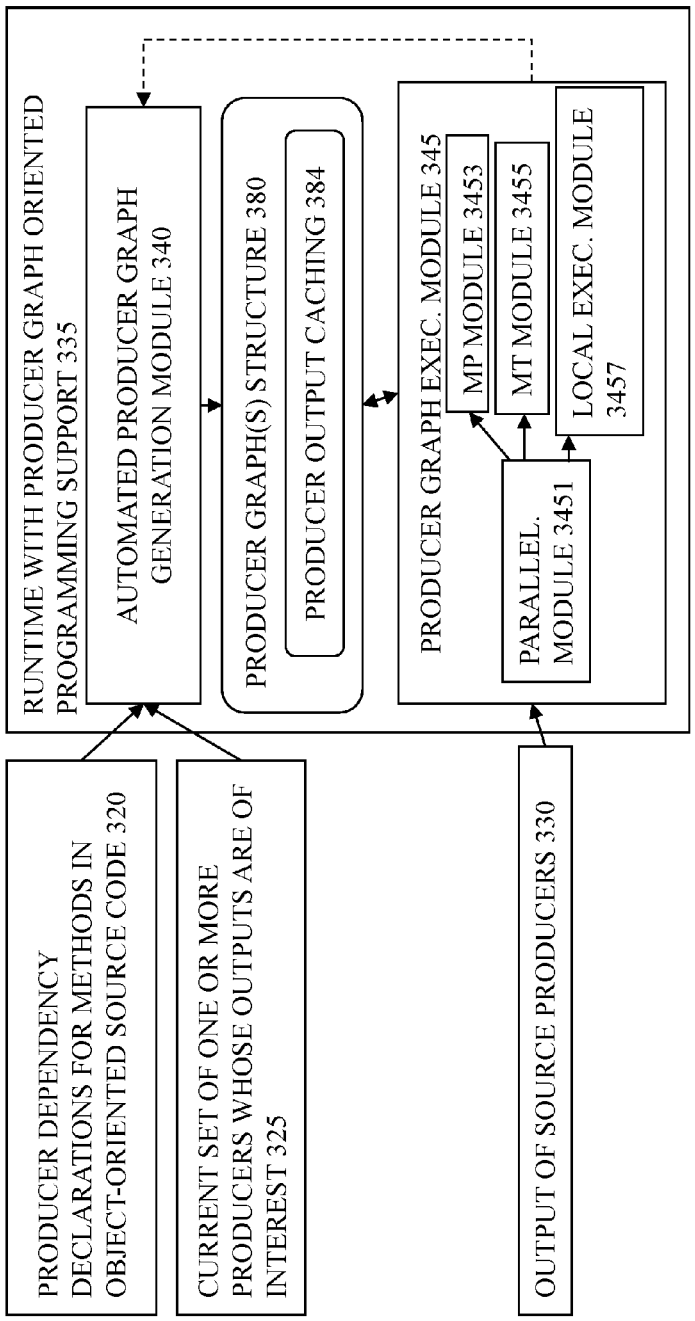


FIGURE 3A

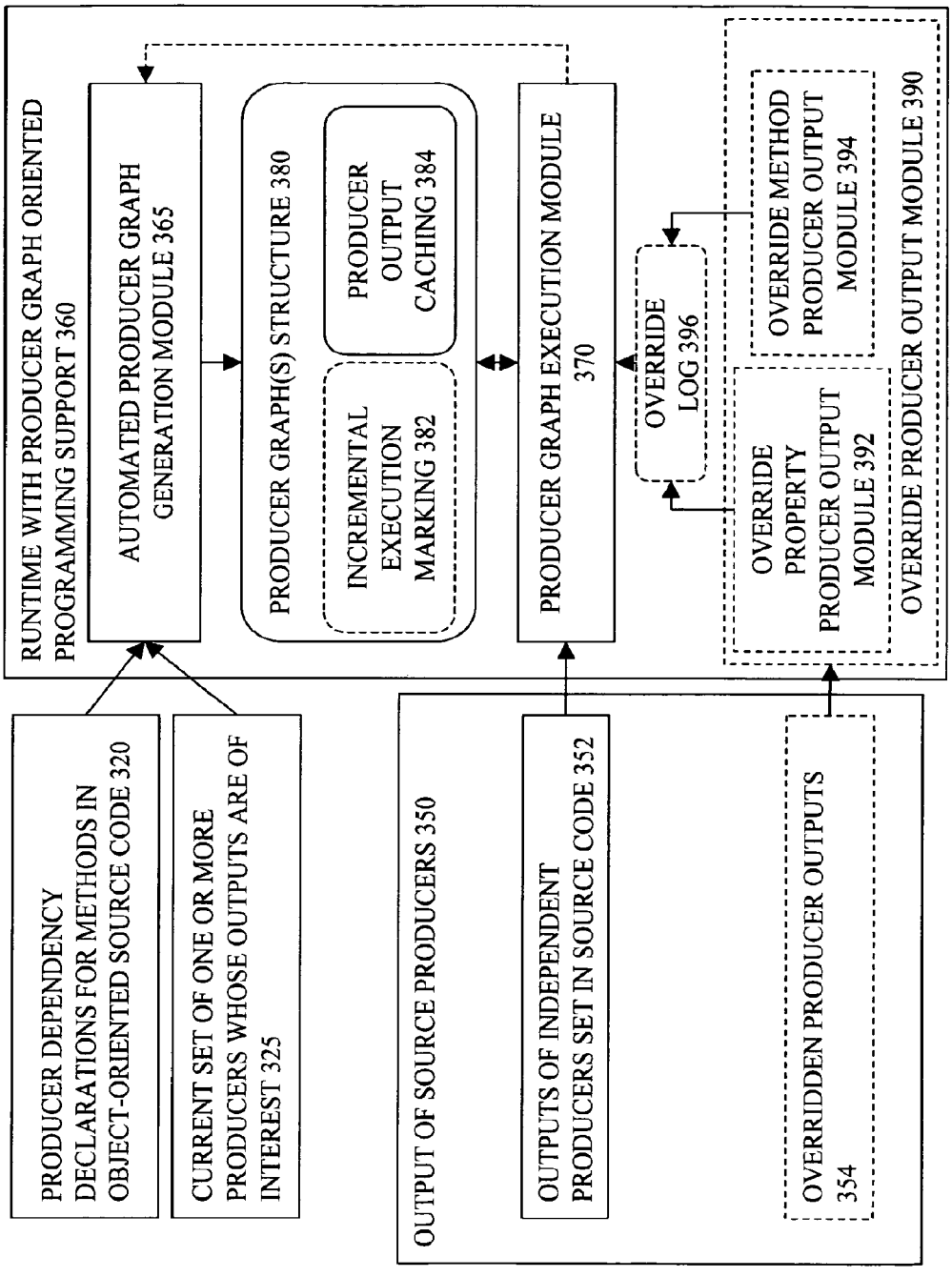

RUNTIME WITH PRODUCER GRAPH ORIENTED PROGRAMMING SUPPORT 360
AUTOMATED PRODUCER GRAPH GENERATION MODULE 365
PRODUCER GRAPH(S) STRUCTURE 380
INCREMENTAL EXECUTION MARKING 382
PRODUCER OUTPUT CACHING 384
PRODUCER GRAPH EXECUTION MODULE 370
OVERRIDE LOG 396
OVERRIDE PRODUCER OUTPUT MODULE 390
OVERRIDE METHOD PRODUCER OUTPUT MODULE 394
OVERRIDE PROPERTY PRODUCER OUTPUT MODULE 392
PRODUCER DEPENDENCY DECLARATIONS FOR METHODS IN OBJECT-ORIENTED SOURCE CODE 320
CURRENT SET OF ONE OR MORE PRODUCERS WHOSE OUTPUTS ARE OF INTEREST 325
OUTPUT OF SOURCE PRODUCERS 350
OUTPUTS OF INDEPENDENT PRODUCERS SET IN SOURCE CODE 352
OVERRIDDEN PRODUCER OUTPUTS 354

FIGURE 3B

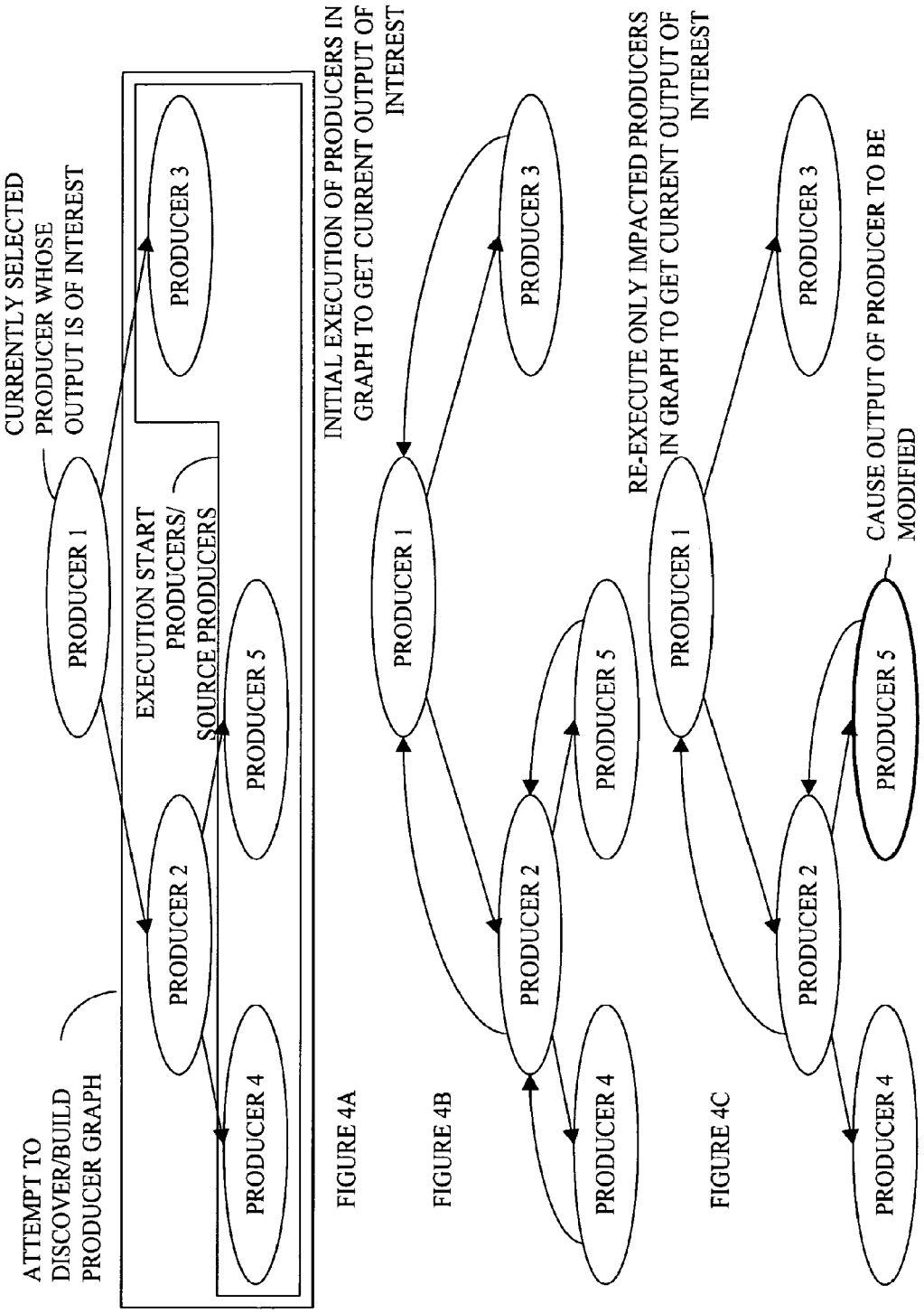


FIGURE 4A

FIGURE 4B

FIGURE 4C

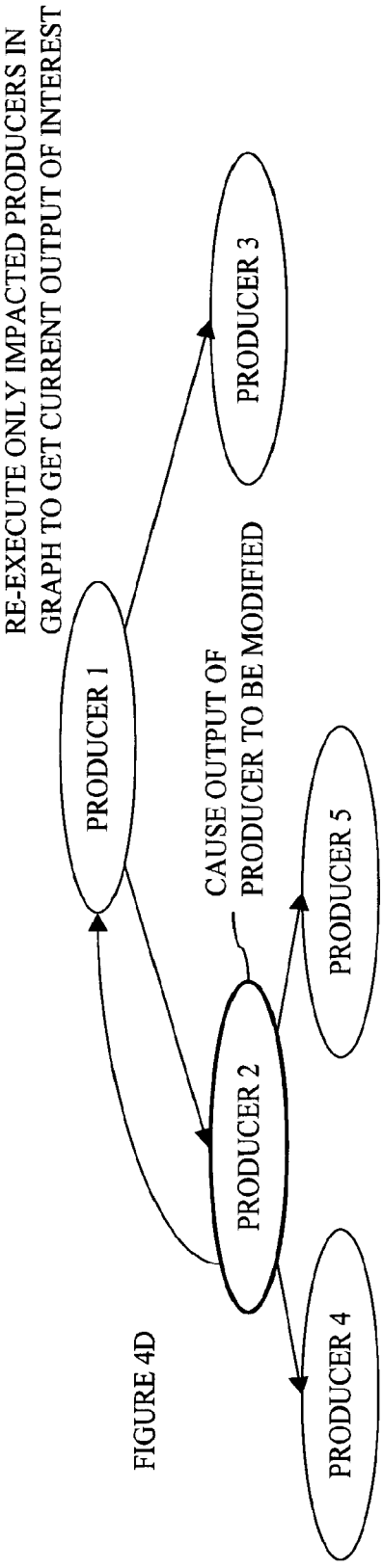


FIGURE 4D

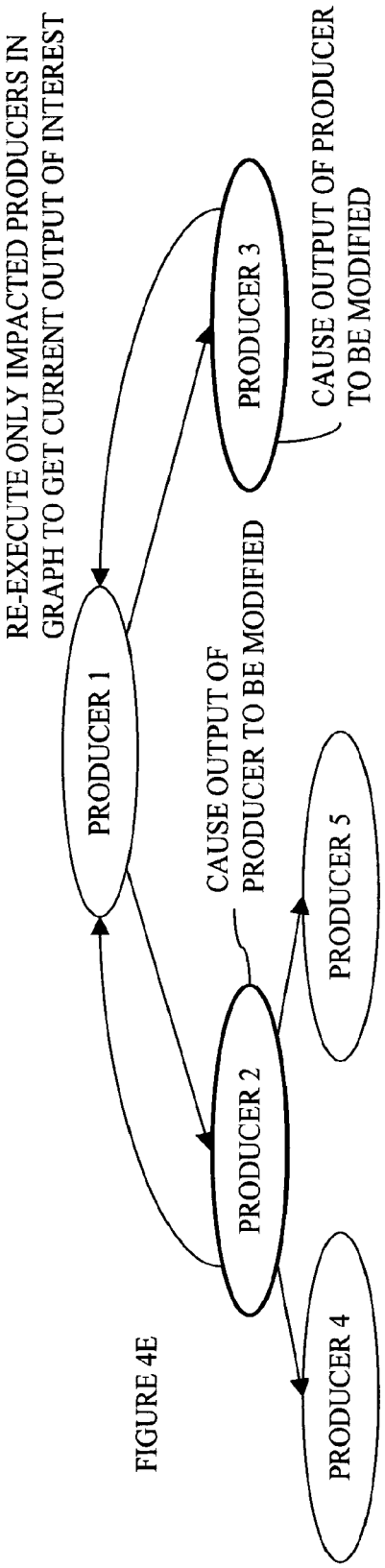


FIGURE 4E

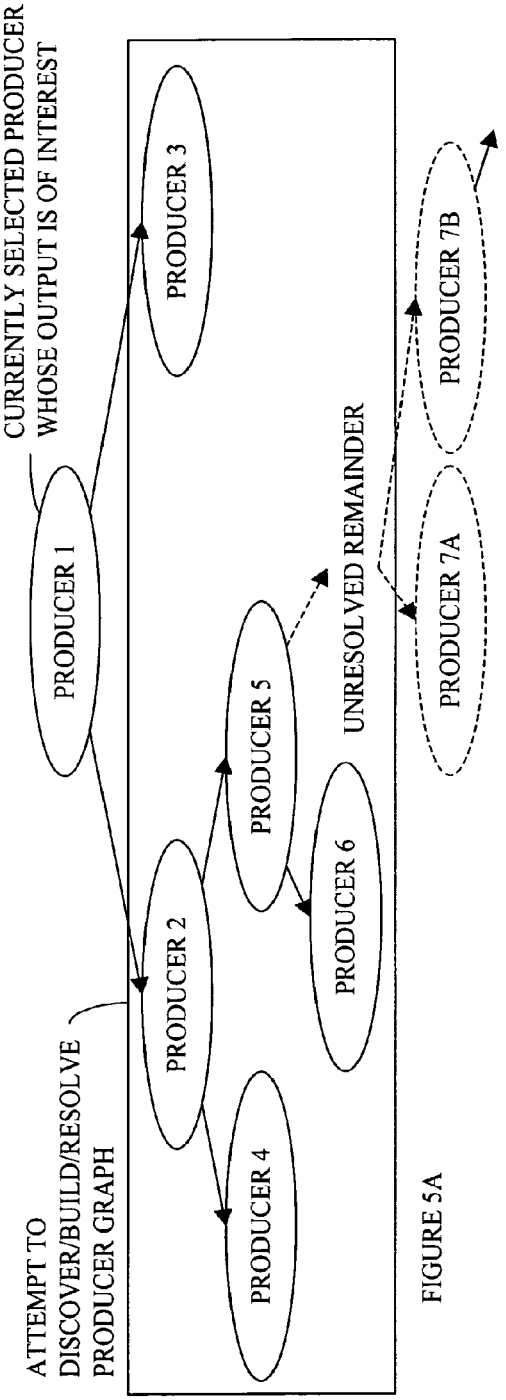


FIGURE 5A

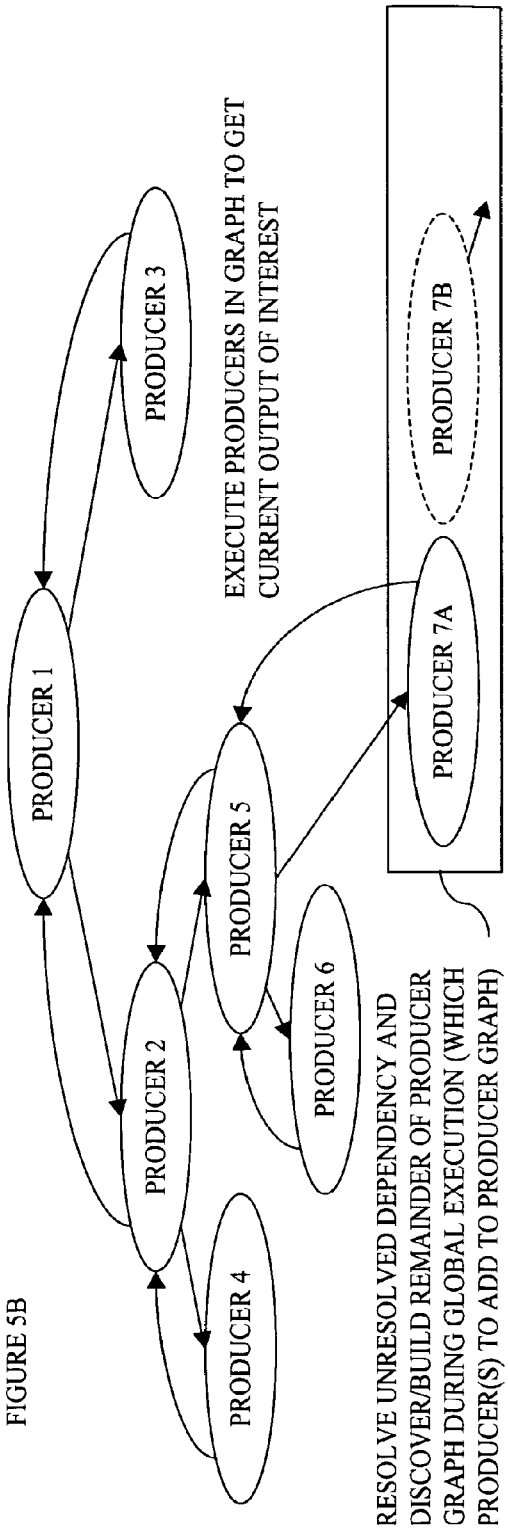
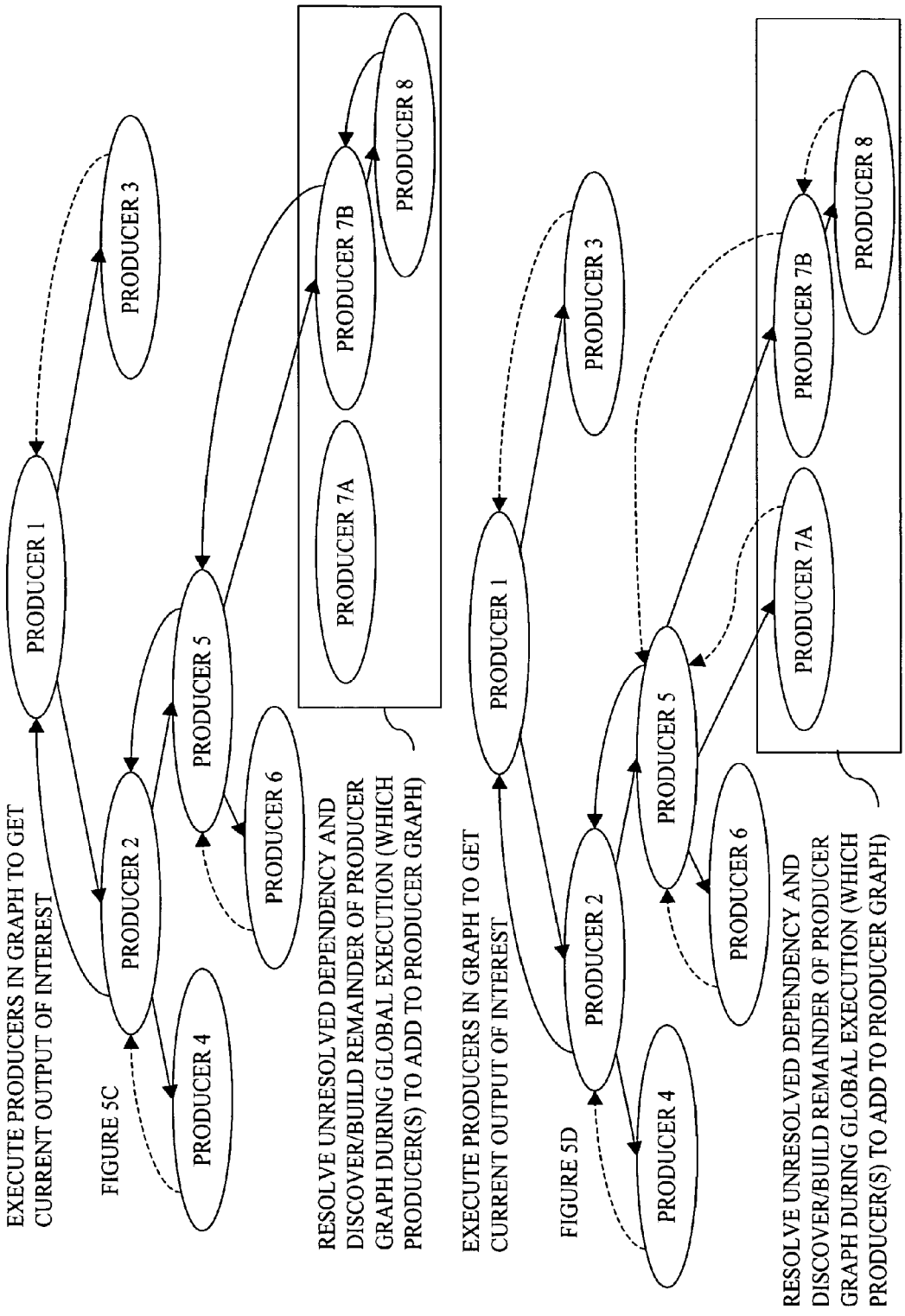


FIGURE 5B


EXECUTE PRODUCERS IN GRAPH TO GET CURRENT OUTPUT OF INTEREST
PRODUCER 1
PRODUCER 2
PRODUCER 3
PRODUCER 4
PRODUCER 5
PRODUCER 6
FIGURE 5C
RESOLVE UNRESOLVED DEPENDENCY AND DISCOVER/BUILD REMAINDER OF PRODUCER GRAPH DURING GLOBAL EXECUTION (WHICH PRODUCER(S) TO ADD TO PRODUCER GRAPH)
PRODUCER 7A
PRODUCER 7B
PRODUCER 8
EXECUTE PRODUCERS IN GRAPH TO GET CURRENT OUTPUT OF INTEREST
PRODUCER 1
PRODUCER 2
PRODUCER 3
PRODUCER 4
PRODUCER 5
PRODUCER 6
FIGURE 5D
RESOLVE UNRESOLVED DEPENDENCY AND DISCOVER/BUILD REMAINDER OF PRODUCER GRAPH DURING GLOBAL EXECUTION (WHICH PRODUCER(S) TO ADD TO PRODUCER GRAPH)
PRODUCER 7A
PRODUCER 7B
PRODUCER 8

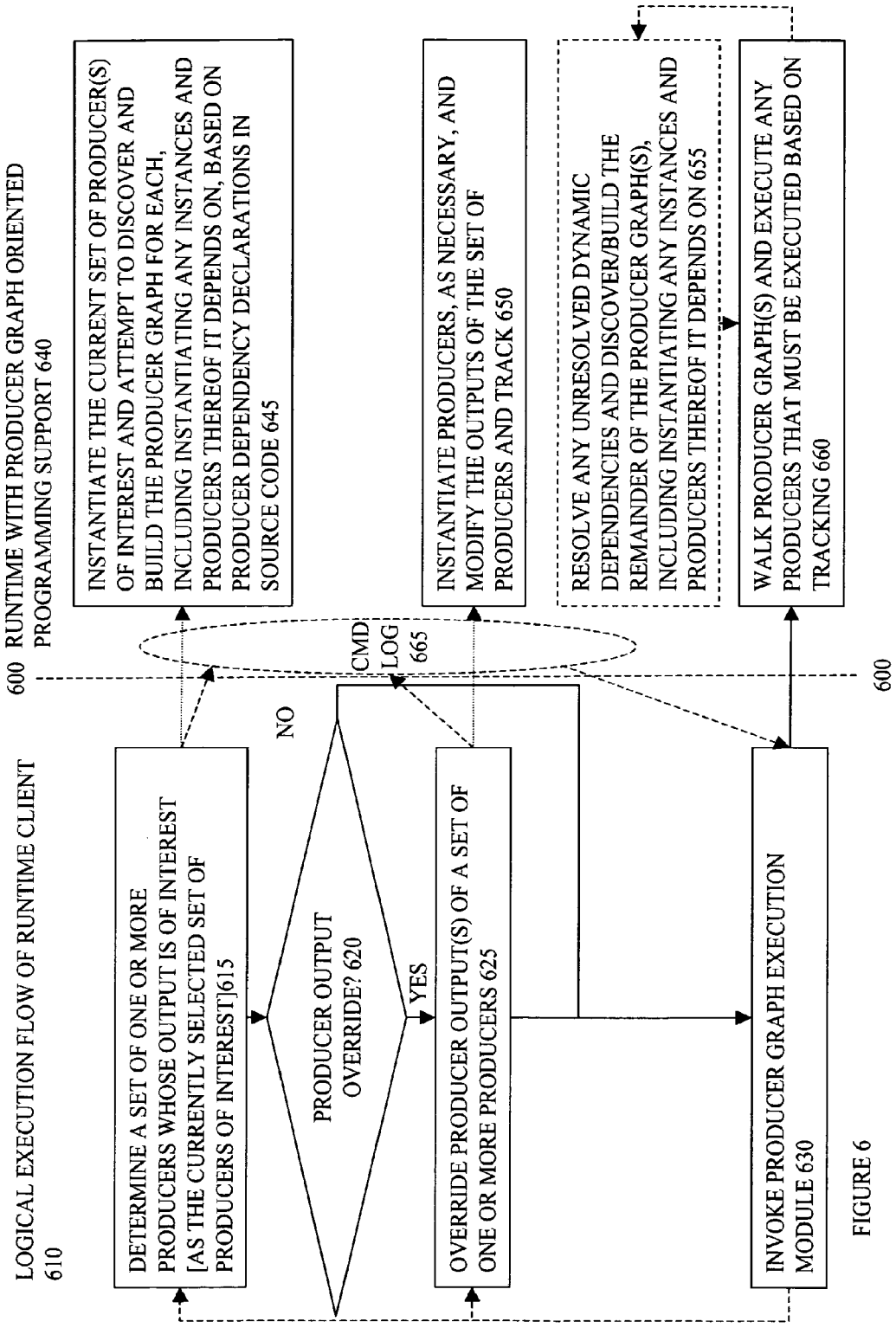

LOGICAL EXECUTION FLOW OF RUNTIME CLIENT
610
600 RUNTIME WITH PRODUCER GRAPH ORIENTED PROGRAMMING SUPPORT 640
600
DETERMINE A SET OF ONE OR MORE PRODUCERS WHOSE OUTPUT IS OF INTEREST [AS THE CURRENTLY SELECTED SET OF PRODUCERS OF INTEREST]615
PRODUCER OUTPUT OVERRIDE? 620
NO
YES
OVERRIDE PRODUCER OUTPUT(S) OF A SET OF ONE OR MORE PRODUCERS 625
INVOKE PRODUCER GRAPH EXECUTION MODULE 630
CMD LOG 665
INSTANTIATE THE CURRENT SET OF PRODUCER(S) OF INTEREST AND ATTEMPT TO DISCOVER AND BUILD THE PRODUCER GRAPH FOR EACH, INCLUDING INSTANTIATING ANY INSTANCES AND PRODUCERS THEREOF IT DEPENDS ON, BASED ON PRODUCER DEPENDENCY DECLARATIONS IN SOURCE CODE 645
INSTANTIATE PRODUCERS, AS NECESSARY, AND MODIFY THE OUTPUTS OF THE SET OF PRODUCERS AND TRACK 650
RESOLVE ANY UNRESOLVED DYNAMIC DEPENDENCIES AND DISCOVER/BUILD THE REMAINDER OF THE PRODUCER GRAPH(S), INCLUDING INSTANTIATING ANY INSTANCES AND PRODUCERS THEREOF IT DEPENDS ON 655
WALK PRODUCER GRAPH(S) AND EXECUTE ANY PRODUCERS THAT MUST BE EXECUTED BASED ON TRACKING 660

FIGURE 6

FIGURE 7A

PRODUCER DEPENDENCY DEC. STATEMENT (ARGUMENTDEP. 1; .... ARG.DEP. N;... FIELDDEP. 1 ...M; SEQ.DEP. 1..L;
UPWARDDEP. 1..P; WEAKLYCONSTRAINEDDEP. 1..Q) 705
METHOD ALPHA (ARG. 1, ... ARG. N) 710

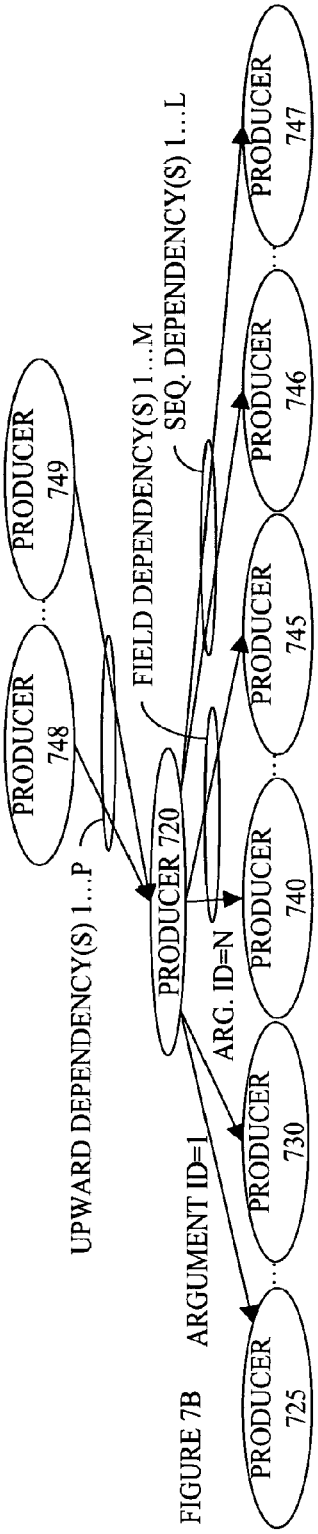
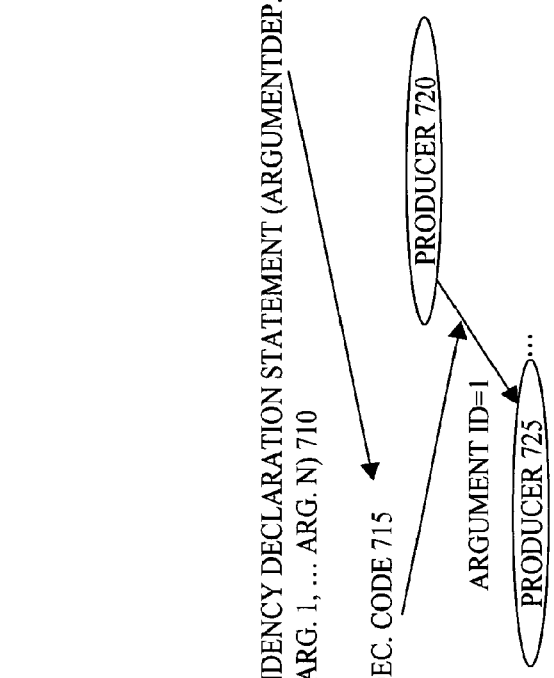
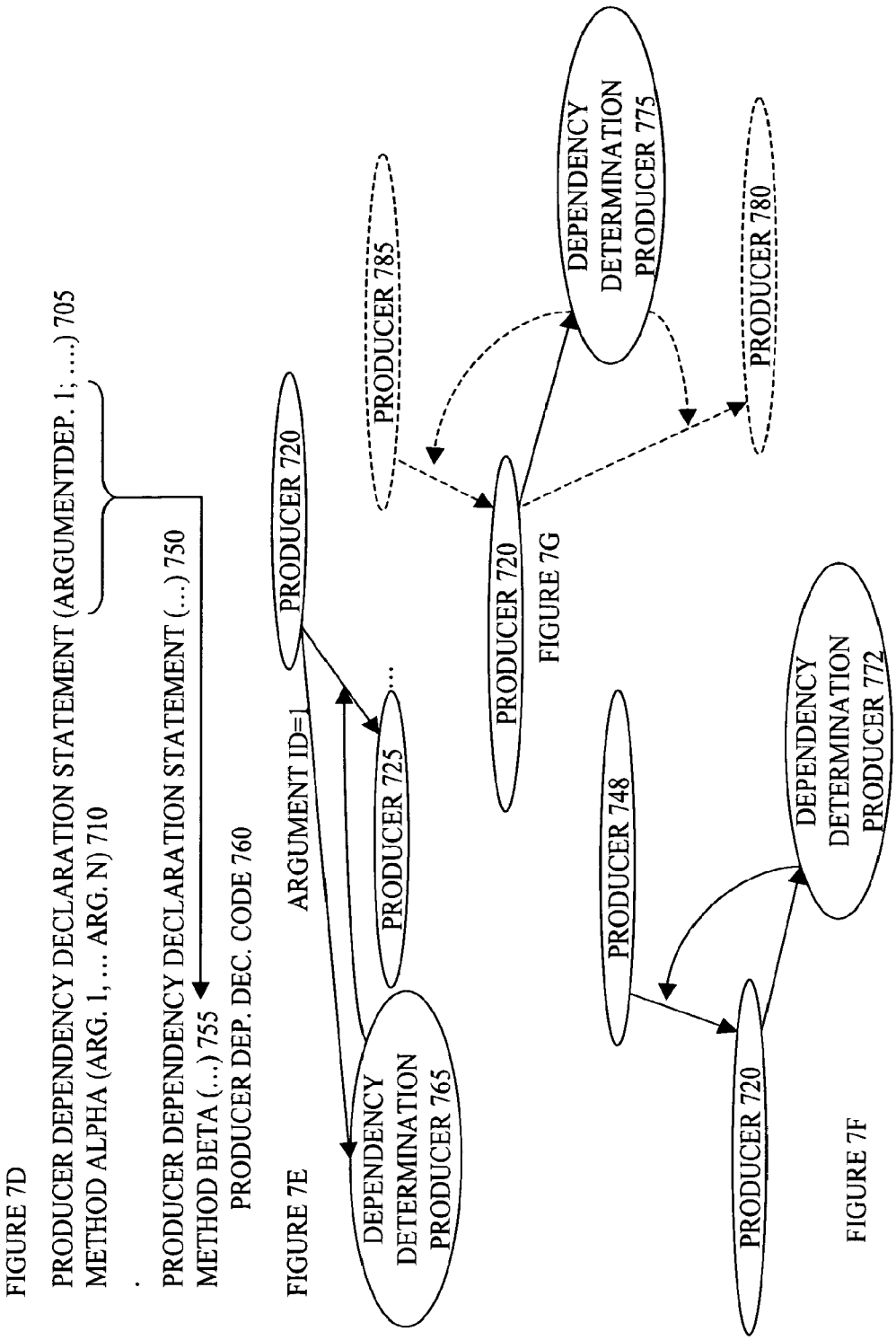


FIGURE 7B

FIGURE 7C

PRODUCER DEPENDENCY DECLARATION STATEMENT (ARGUMENTDEP. 1; ....) 705
METHOD ALPHA (ARG. 1, ... ARG. N) 710
.
PRODUCER DEP. DEC. CODE 715




PRODUCER DEPENDENCY DECLARATION STATEMENT (ARGUMENTDEP. 1; ....) 705
METHOD ALPHA (ARG. 1, ... ARG. N) 710
.
PRODUCER DEPENDENCY DECLARATION STATEMENT (...) 750
METHOD BETA (...) 755
PRODUCER DEP. DEC. CODE 760
FIGURE 7D
ARGUMENT ID=1
PRODUCER 720
PRODUCER 725
...
DEPENDENCY DETERMINATION PRODUCER 765
FIGURE 7E
PRODUCER 785
PRODUCER 720
DEPENDENCY DETERMINATION PRODUCER 775
PRODUCER 780
FIGURE 7G
PRODUCER 748
PRODUCER 720
DEPENDENCY DETERMINATION PRODUCER 772
FIGURE 7F

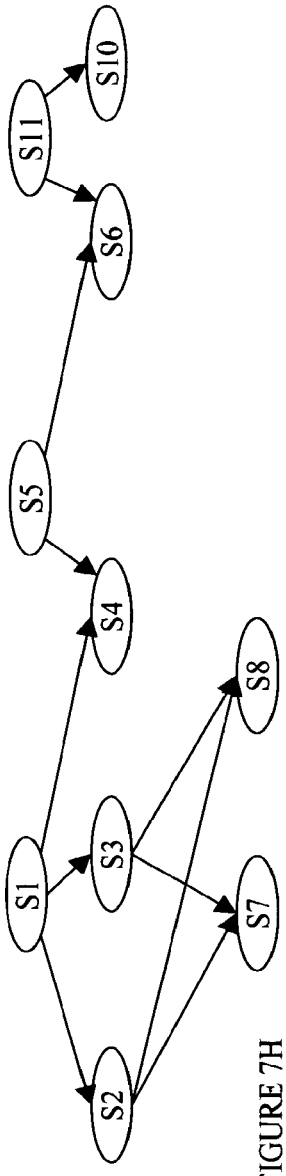


FIGURE 7H

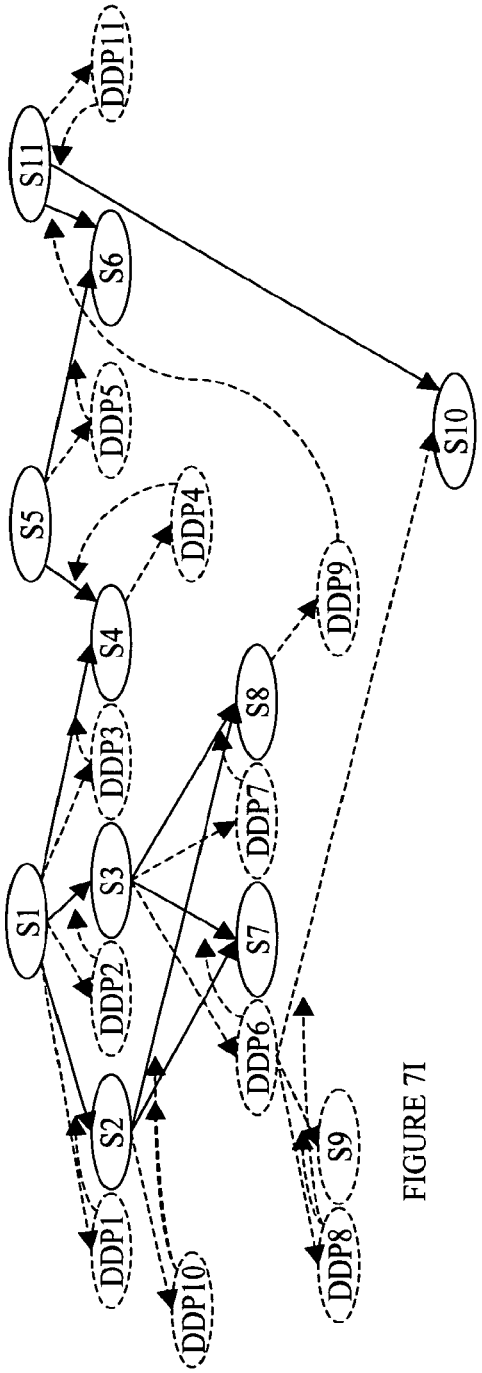


FIGURE 7I

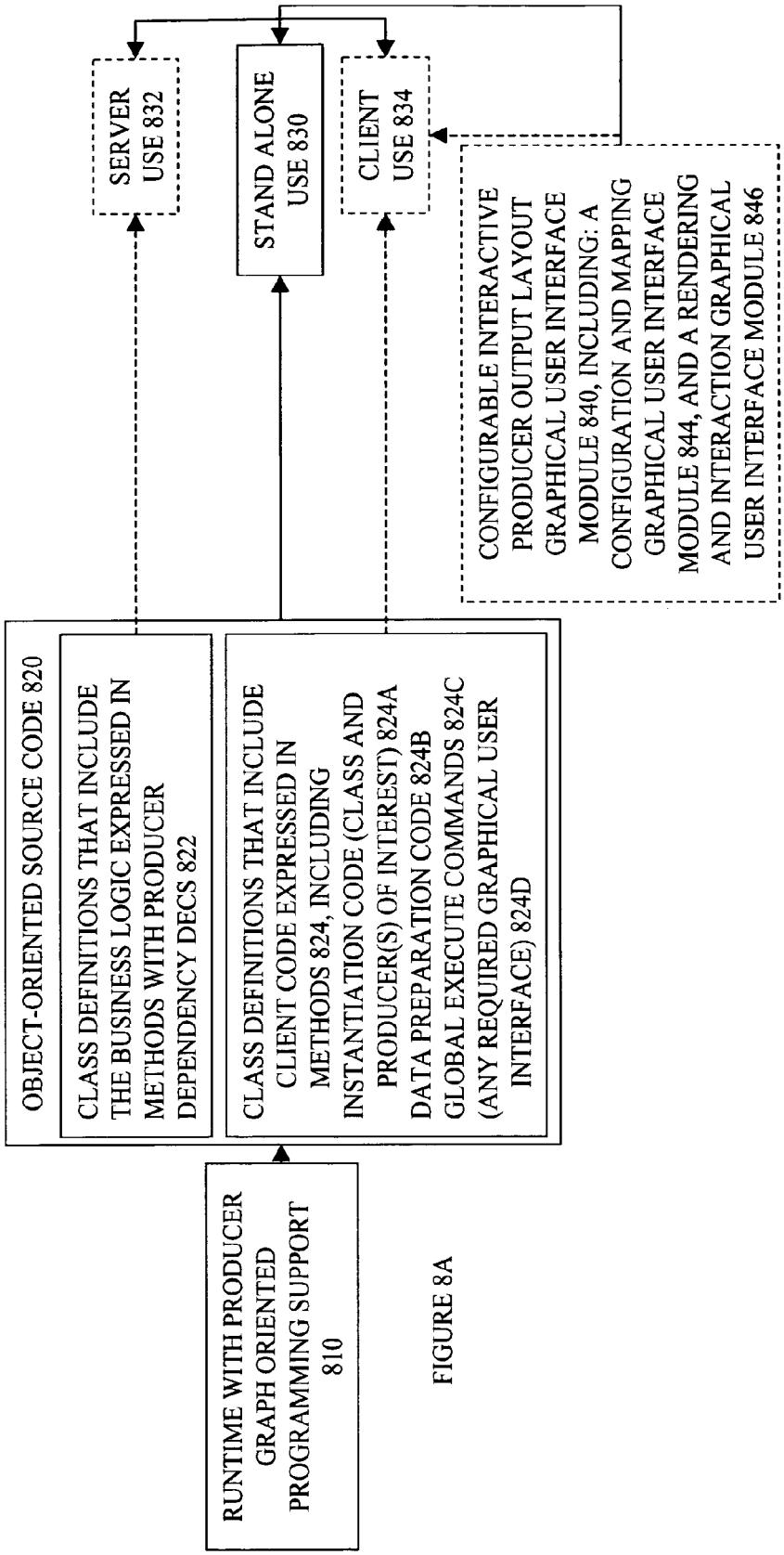

SERVER USE 832
STAND ALONE USE 830
CLIENT USE 834
CONFIGURABLE INTERACTIVE PRODUCER OUTPUT LAYOUT GRAPHICAL USER INTERFACE MODULE 840, INCLUDING: A CONFIGURATION AND MAPPING GRAPHICAL USER INTERFACE MODULE 844, AND A RENDERING AND INTERACTION GRAPHICAL USER INTERFACE MODULE 846
OBJECT-ORIENTED SOURCE CODE 820
CLASS DEFINITIONS THAT INCLUDE THE BUSINESS LOGIC EXPRESSED IN METHODS WITH PRODUCER DEPENDENCY DECS 822
CLASS DEFINITIONS THAT INCLUDE CLIENT CODE EXPRESSED IN METHODS 824, INCLUDING INSTANTIATION CODE (CLASS AND PRODUCER(S) OF INTEREST) 824A DATA PREPARATION CODE 824B GLOBAL EXECUTE COMMANDS 824C (ANY REQUIRED GRAPHICAL USER INTERFACE) 824D
RUNTIME WITH PRODUCER GRAPH ORIENTED PROGRAMMING SUPPORT 810

FIGURE 8A

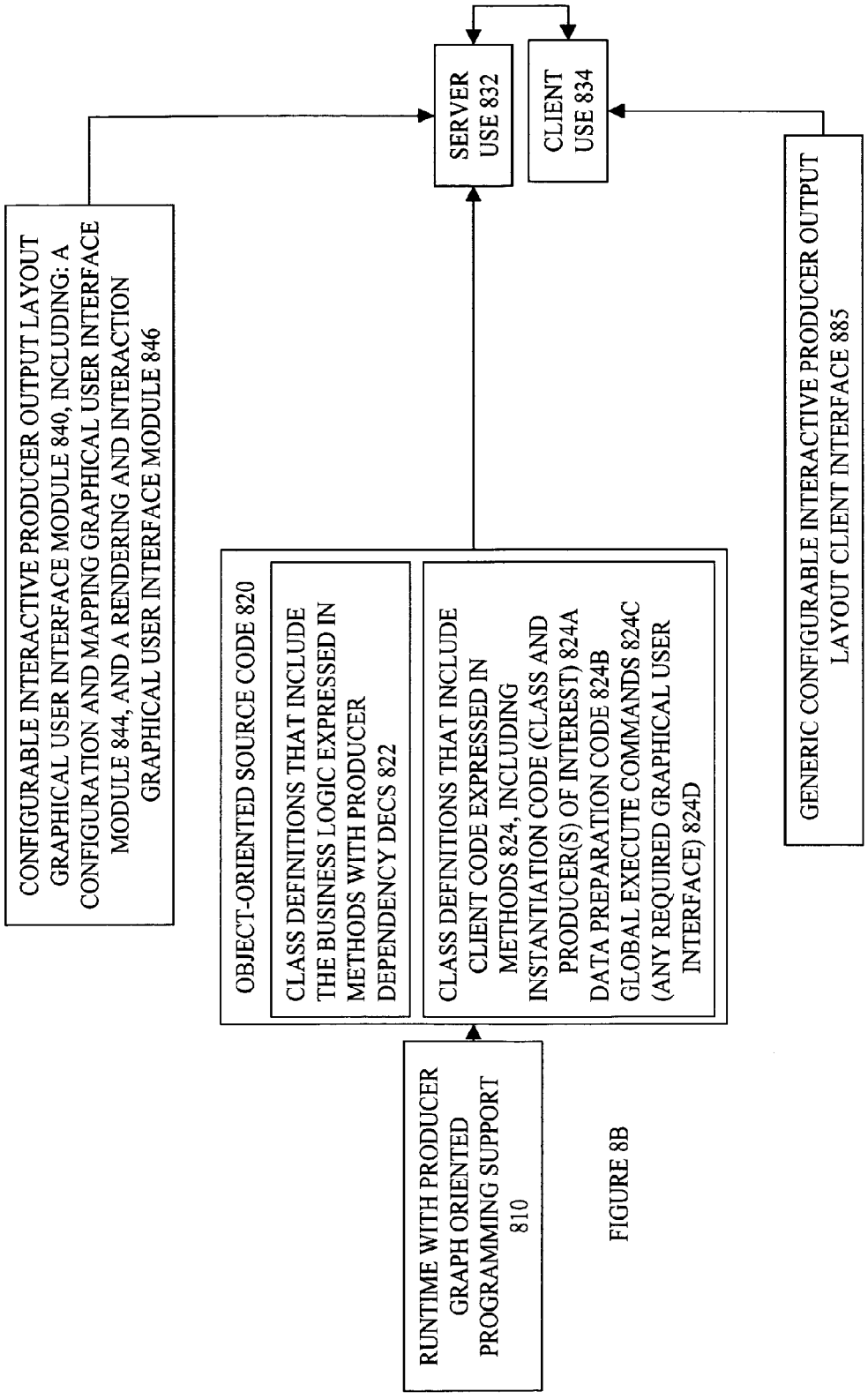

SERVER USE 832
CLIENT USE 834
CONFIGURABLE INTERACTIVE PRODUCER OUTPUT LAYOUT GRAPHICAL USER INTERFACE MODULE 840, INCLUDING: A CONFIGURATION AND MAPPING GRAPHICAL USER INTERFACE MODULE 844, AND A RENDERING AND INTERACTION GRAPHICAL USER INTERFACE MODULE 846
OBJECT-ORIENTED SOURCE CODE 820
CLASS DEFINITIONS THAT INCLUDE THE BUSINESS LOGIC EXPRESSED IN METHODS WITH PRODUCER DEPENDENCY DECS 822
CLASS DEFINITIONS THAT INCLUDE CLIENT CODE EXPRESSED IN METHODS 824, INCLUDING INSTANTIATION CODE (CLASS AND PRODUCER(S) OF INTEREST) 824A DATA PREPARATION CODE 824B GLOBAL EXECUTE COMMANDS 824C (ANY REQUIRED GRAPHICAL USER INTERFACE) 824D
GENERIC CONFIGURABLE INTERACTIVE PRODUCER OUTPUT LAYOUT CLIENT INTERFACE 885
RUNTIME WITH PRODUCER GRAPH ORIENTED PROGRAMMING SUPPORT 810

FIGURE 8B

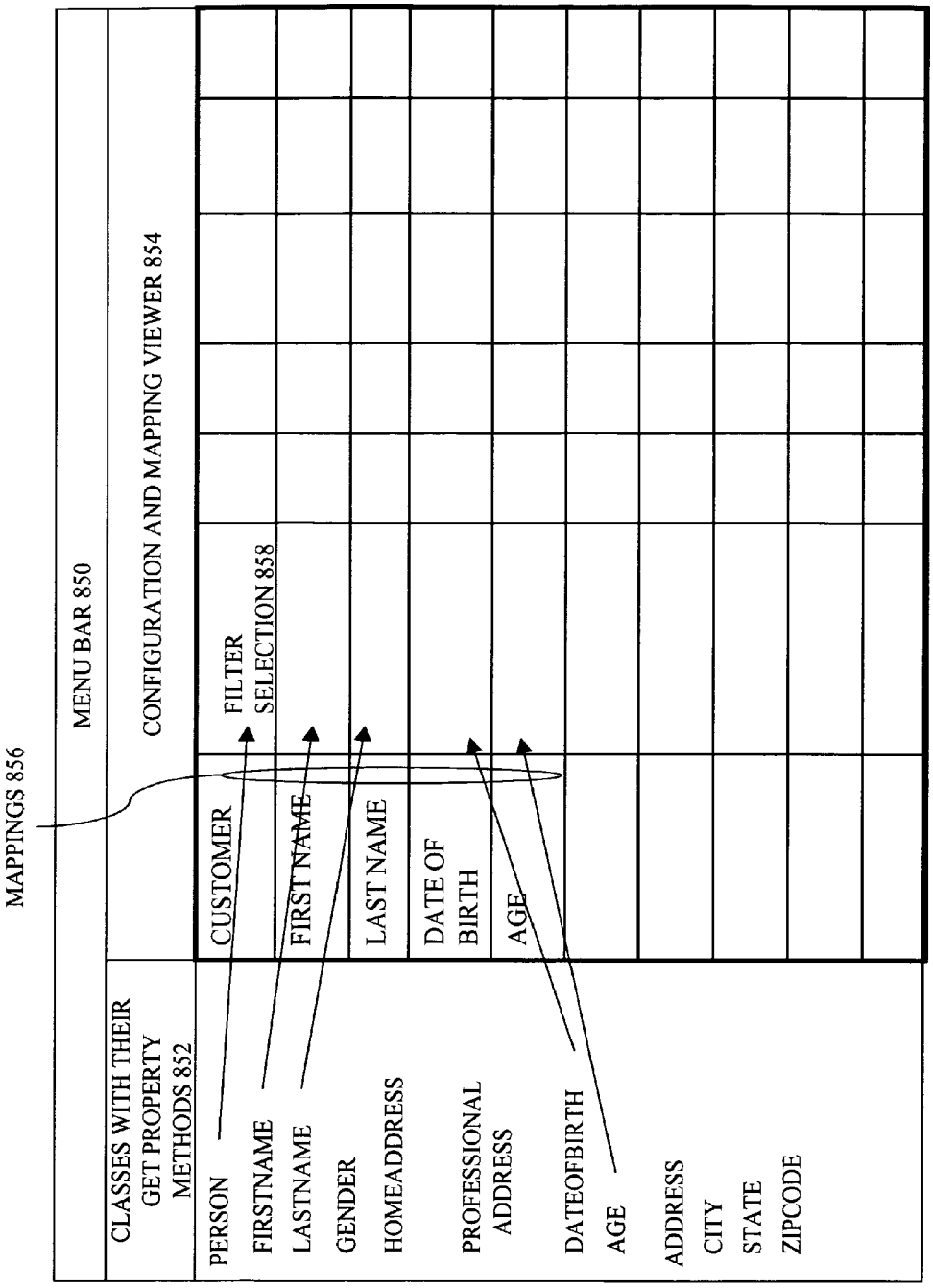

MAPPINGS 856
MENU BAR 850
CONFIGURATION AND MAPPING VIEWER 854
CLASSES WITH THEIR GET PROPERTY METHODS 852
PERSON
FIRSTNAME
LASTNAME
GENDER
HOMEADDRESS
PROFESSIONAL ADDRESS
DATEOFBIRTH
AGE
ADDRESS
CITY
STATE
ZIPCODE
CUSTOMER
FILTER SELECTION 858
FIRST NAME
LAST NAME
DATE OF BIRTH
AGE

FIGURE 8C

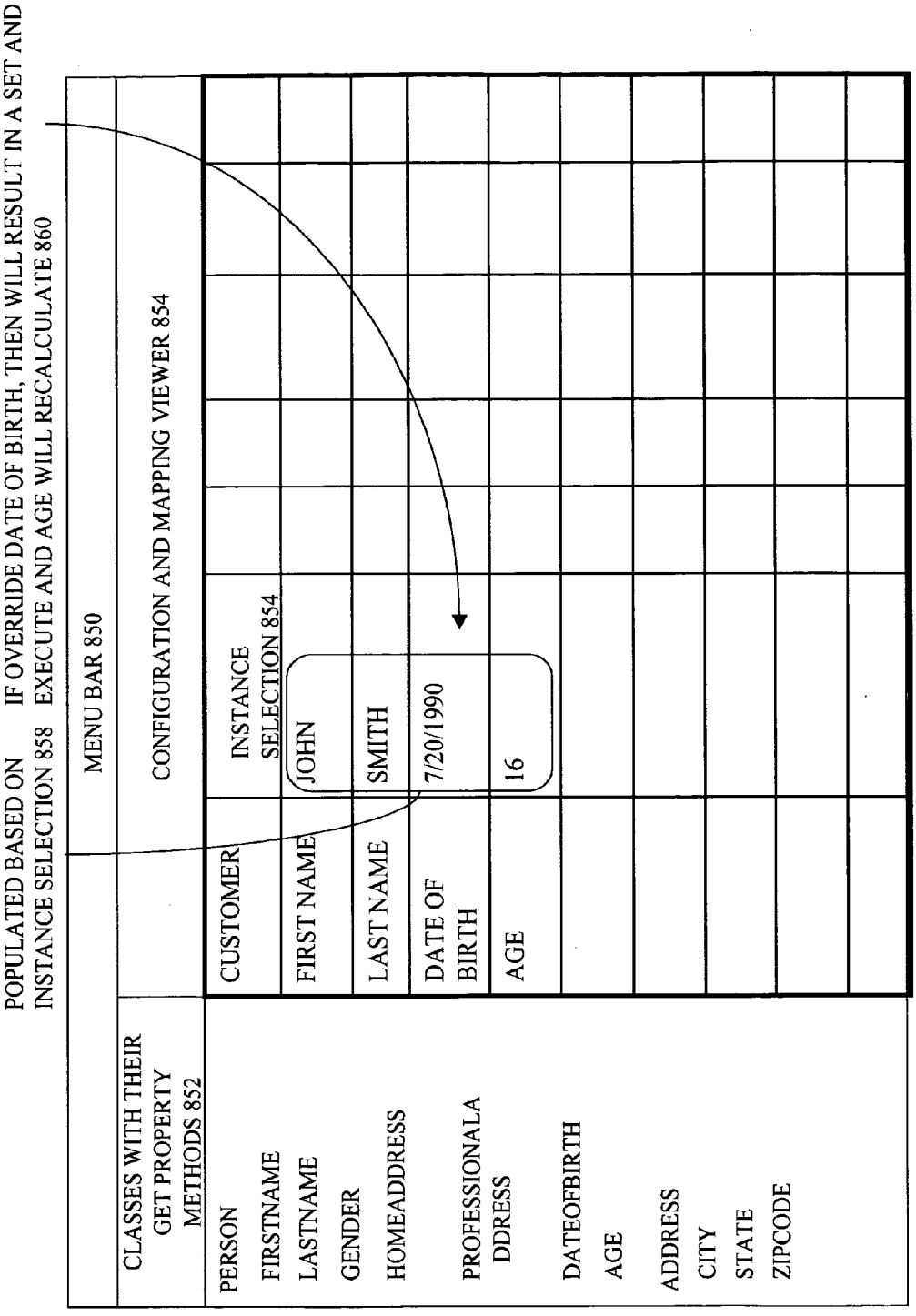

POPULATED BASED ON INSTANCE SELECTION 858
IF OVERRIDE DATE OF BIRTH, THEN WILL RESULT IN A SET AND EXECUTE AND AGE WILL RECALCULATE 860
MENU BAR 850
CONFIGURATION AND MAPPING VIEWER 854
CLASSES WITH THEIR GET PROPERTY METHODS 852
PERSON
FIRSTNAME
LASTNAME
GENDER
HOMEADDRESS
PROFESSIONALADDRESS
DATEOFBIRTH
AGE
ADDRESS
CITY
STATE
ZIPCODE
CUSTOMER
INSTANCE SELECTION 854
FIRST NAME
JOHN
LAST NAME
SMITH
DATE OF BIRTH
7/20/1990
AGE
16

FIGURE 8D

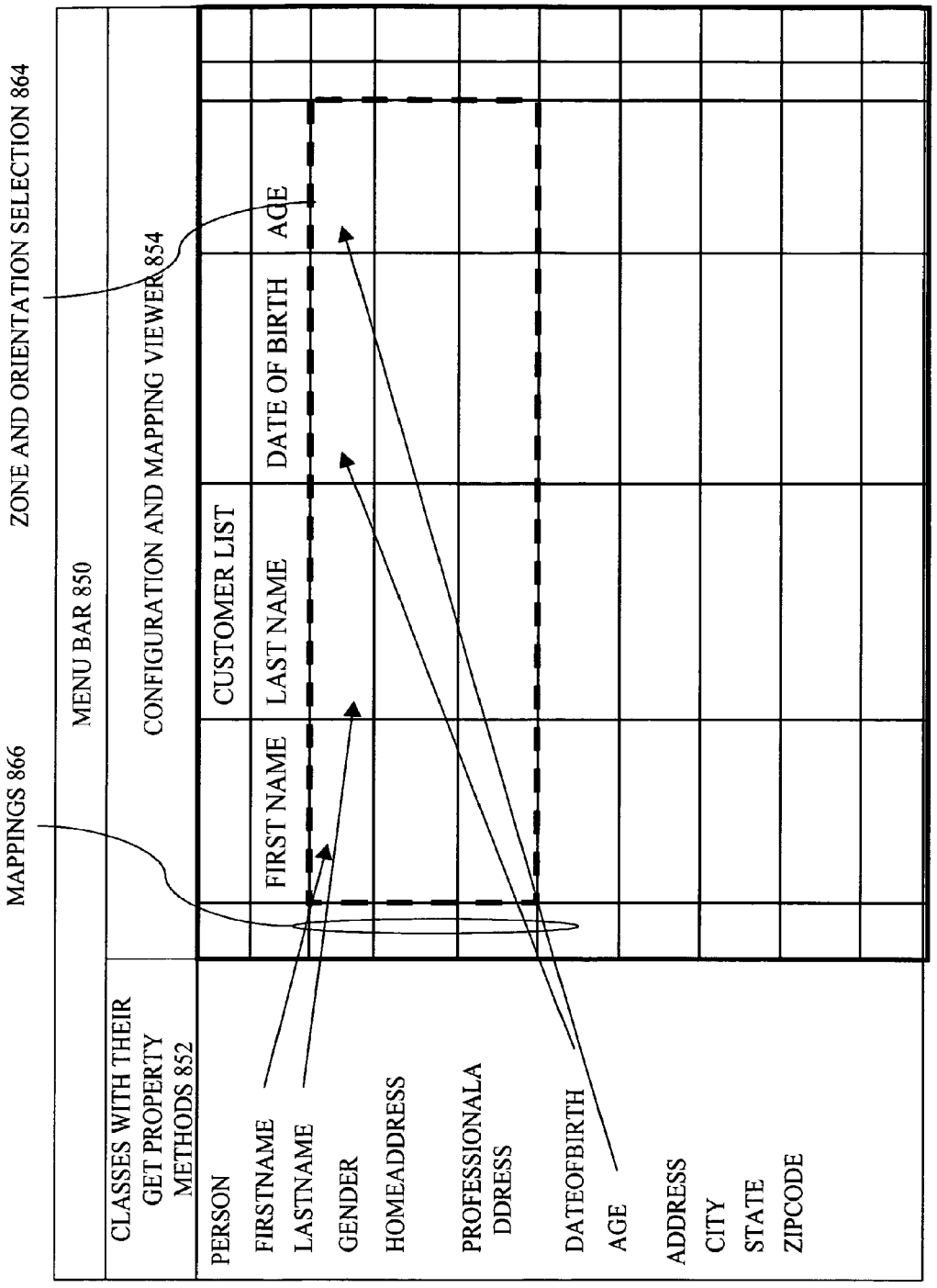

ZONE AND ORIENTATION SELECTION 864
MAPPINGS 866
MENU BAR 850
CONFIGURATION AND MAPPING VIEWER 854
CLASSES WITH THEIR GET PROPERTY METHODS 852
CUSTOMER LIST
FIRST NAME
LAST NAME
DATE OF BIRTH
AGE
PERSON
FIRSTNAME
LASTNAME
GENDER
HOMEADDRESS
PROFESSIONALADDRESS
DATEOFBIRTH
AGE
ADDRESS
CITY
STATE
ZIPCODE

FIGURE 8E

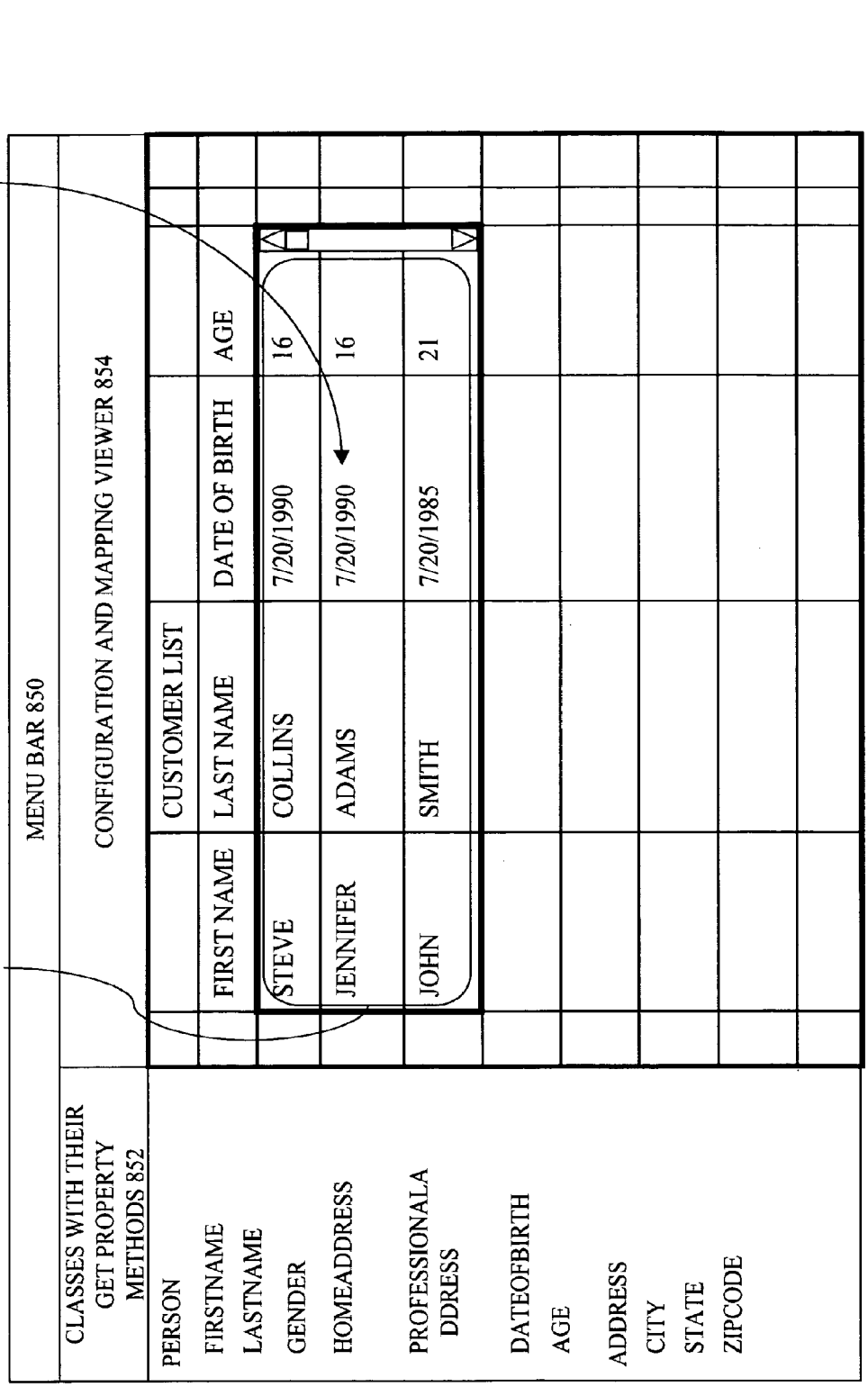

POPULATED BASED ON INSTANCES OF CLASS PERSON 868
IF OVERRIDE DATE OF BIRTH, THEN WILL RESULT IN A SET AND EXECUTE AND AGE WILL RECALCULATE 870
MENU BAR 850
CLASSES WITH THEIR GET PROPERTY METHODS 852
CONFIGURATION AND MAPPING VIEWER 854
PERSON
FIRSTNAME
LASTNAME
GENDER
HOMEADDRESS
PROFESSIONALADDRESS
DATEOFBIRTH
AGE
ADDRESS
CITY
STATE
ZIPCODE
CUSTOMER LIST
FIRST NAME
LAST NAME
DATE OF BIRTH
AGE
STEVE
COLLINS
7/20/1990
16
JENNIFER
ADAMS
7/20/1990
16
JOHN
SMITH
7/20/1985
21

FIGURE 8F

OBJECT ORIENTED SOURCE CODE WITH PRODUCER DEPENDENCY DECLARATIONS FOR METHODS 905
RUNTIME WITH PRODUCER GRAPH ORIENTED PROGRAMMING SUPPORT 910
RUNTIME WITH CLASS LOADING, DYNAMIC CLASS INSTANTIATION, DYNAMIC SINGLE METHOD INVOCATION, AND CLASS/METHOD INTROSPECTION 915
OPERATING SYSTEM 920

FIGURE 9A

OBJECT ORIENTED SOURCE CODE WITH PRODUCER DEPENDENCY DECLARATIONS FOR METHODS 925
RUNTIME WITH CLASS LOADING, DYNAMIC CLASS INSTANTIATION, DYNAMIC SINGLE METHOD INVOCATION, AND CLASS/METHOD INTROSPECTION , AS WELL AS WITH PRODUCER GRAPH ORIENTED PROGRAMMING SUPPORT 930
OPERATING SYSTEM 935

FIGURE 9B

OBJECT ORIENTED SOURCE CODE WITH PRODUCER DEPENDENCY DECLARATIONS FOR METHODS 940
OPERATING SYSTEM RUNTIME WITH CLASS LOADING, DYNAMIC CLASS INSTANTIATION, DYNAMIC SINGLE METHOD INVOCATION, AND CLASS/METHOD INTROSPECTION, AS WELL AS WITH PRODUCER GRAPH ORIENTED PROGRAMMING SUPPORT 945

FIGURE 9C

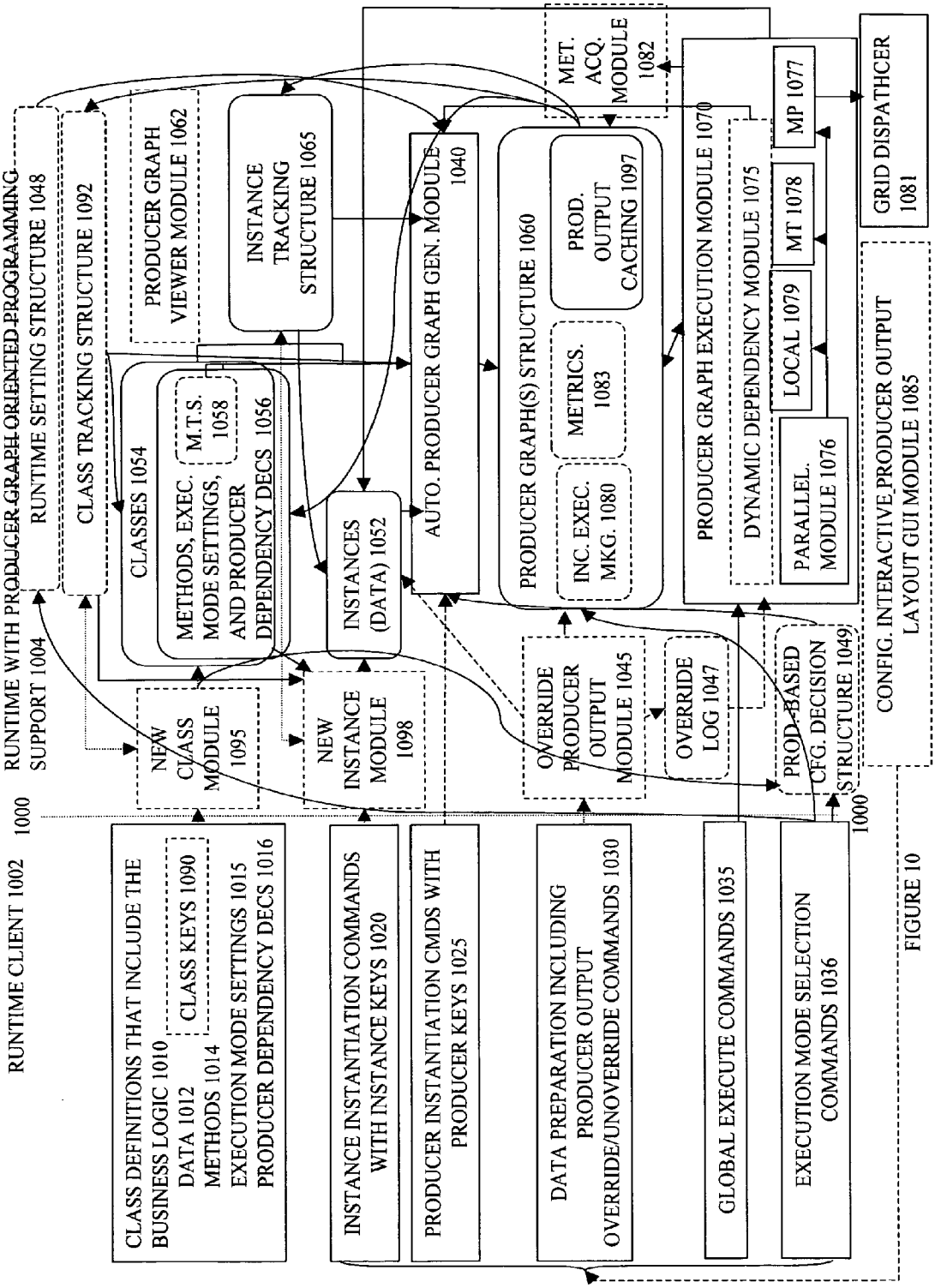

RUNTIME CLIENT 1002
1000
RUNTIME WITH PRODUCER GRAPH ORIENTED PROGRAMMING SUPPORT 1004
RUNTIME SETTING STRUCTURE 1048
CLASS TRACKING STRUCTURE 1092
PRODUCER GRAPH VIEWER MODULE 1062
INSTANCE TRACKING STRUCTURE 1065
MET. ACQ. MODULE 1082
CLASSES 1054
METHODS, EXEC. MODE SETTINGS, AND PRODUCER DEPENDENCY DECS 1056
M.T.S. 1058
AUTO. PRODUCER GRAPH GEN. MODULE 1040
PRODUCER GRAPH(S) STRUCTURE 1060
PROD. OUTPUT CACHING 1097
METRICS. 1083
INC. EXEC. MKG. 1080
PRODUCER GRAPH EXECUTION MODULE 1070
DYNAMIC DEPENDENCY MODULE 1075
MP 1077
MT 1078
LOCAL 1079
PARALLEL. MODULE 1076
GRID DISPATHCER 1081
INSTANCES (DATA) 1052
NEW CLASS MODULE 1095
NEW INSTANCE MODULE 1098
OVERRIDE PRODUCER OUTPUT MODULE 1045
OVERRIDE LOG 1047
PROD.-BASED CFG. DECISION STRUCTURE 1049
CONFIG. INTERACTIVE PRODUCER OUTPUT LAYOUT GUI MODULE 1085
1000
CLASS DEFINITIONS THAT INCLUDE THE BUSINESS LOGIC 1010
DATA 1012
METHODS 1014
CLASS KEYS 1090
EXECUTION MODE SETTINGS 1015
PRODUCER DEPENDENCY DECS 1016
INSTANCE INSTANTIATION COMMANDS WITH INSTANCE KEYS 1020
PRODUCER INSTANTIATION CMDS WITH PRODUCER KEYS 1025
DATA PREPARATION INCLUDING PRODUCER OUTPUT OVERRIDE/UNOVERRIDE COMMANDS 1030
GLOBAL EXECUTE COMMANDS 1035
EXECUTION MODE SELECTION COMMANDS 1036

FIGURE 10

CLASS KEY 1110	CLASS REFERENCE 1115

FIGURE 11A

INSTANCE KEY 1120	INSTANCE REFERENCE 1125

FIGURE 11B

CLASS REF. 1135	INSTANCE REF. 1140	METHOD REF. 1145	PARENT PRODUCER(S) LINK(S) 1150 INCLUDING FOR EACH LINK A PARENT PRODUCER REFERENCE AND A DEPENDENCY DETERMINATION PRODUCER REFERENCE	CHILD PRODUCER(S) LINK(S) 1160, INCLUDING FOR EACH LINK CHILD PRODUCER REFERENCE(S), A DEPENDENCY DETERMINATION PRODUCER REFERENCE, A LINK MODE AND A STICKY INDICATOR	PRODUCER OUTPUT CACHING & OVERRIDE PRODUCER OUTPUT INDICATIONS 1170	PRODUCER EXECUTION MODE SETTING 1173	PRODUCER METRICS 1175	INCREMENTAL EXECUTION MARKING 1180

FIGURE 11C

METHOD KEY 1190	METHOD REFERENCE 1192	ARG. 1194	FIELD 1196	SEQ. 1195	UPWARD 1193	WEAKLY CONSTRAINED 1199	OUTPUT CLASS 1197	ADDITIONAL ANNOTATIONS 1198

FIGURE 11D

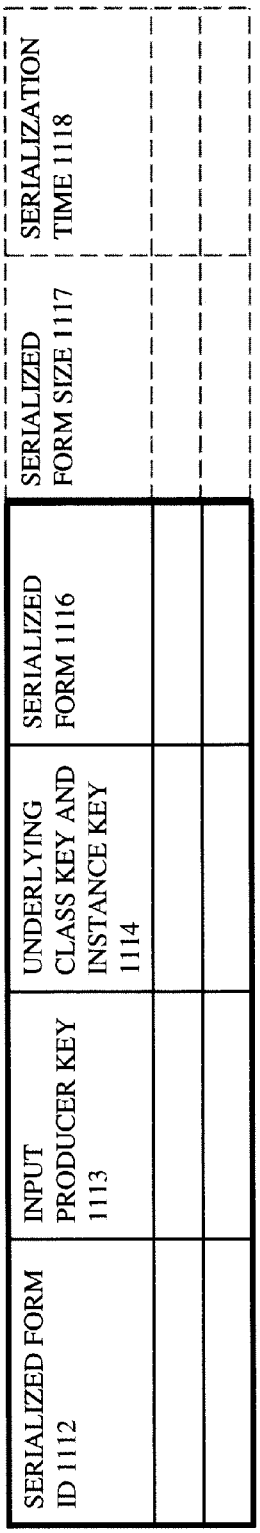


FIGURE 11E

SERIALIZED FORM MAP CAN BE GLOBAL OR SPECIFIC TO EACH JOB

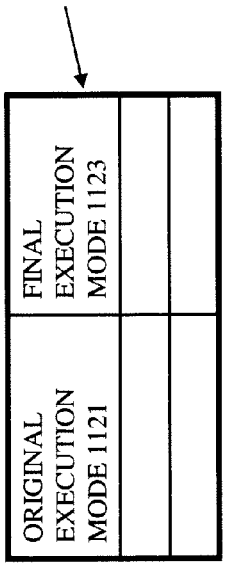


FIGURE 11F

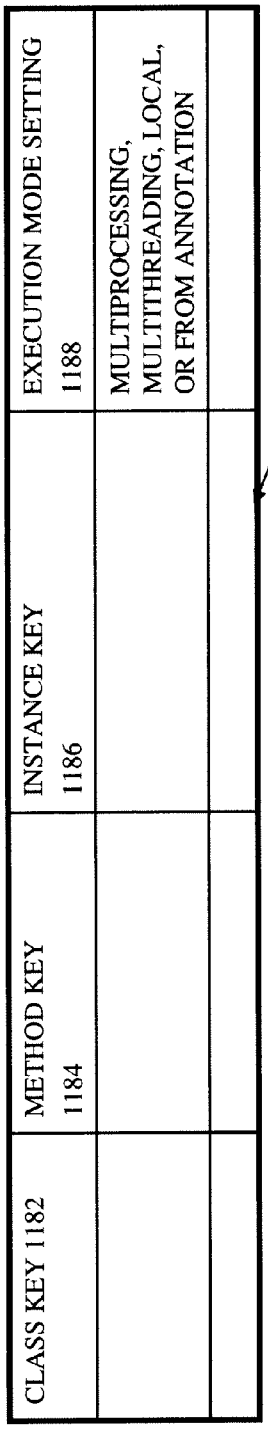


FIGURE 11G

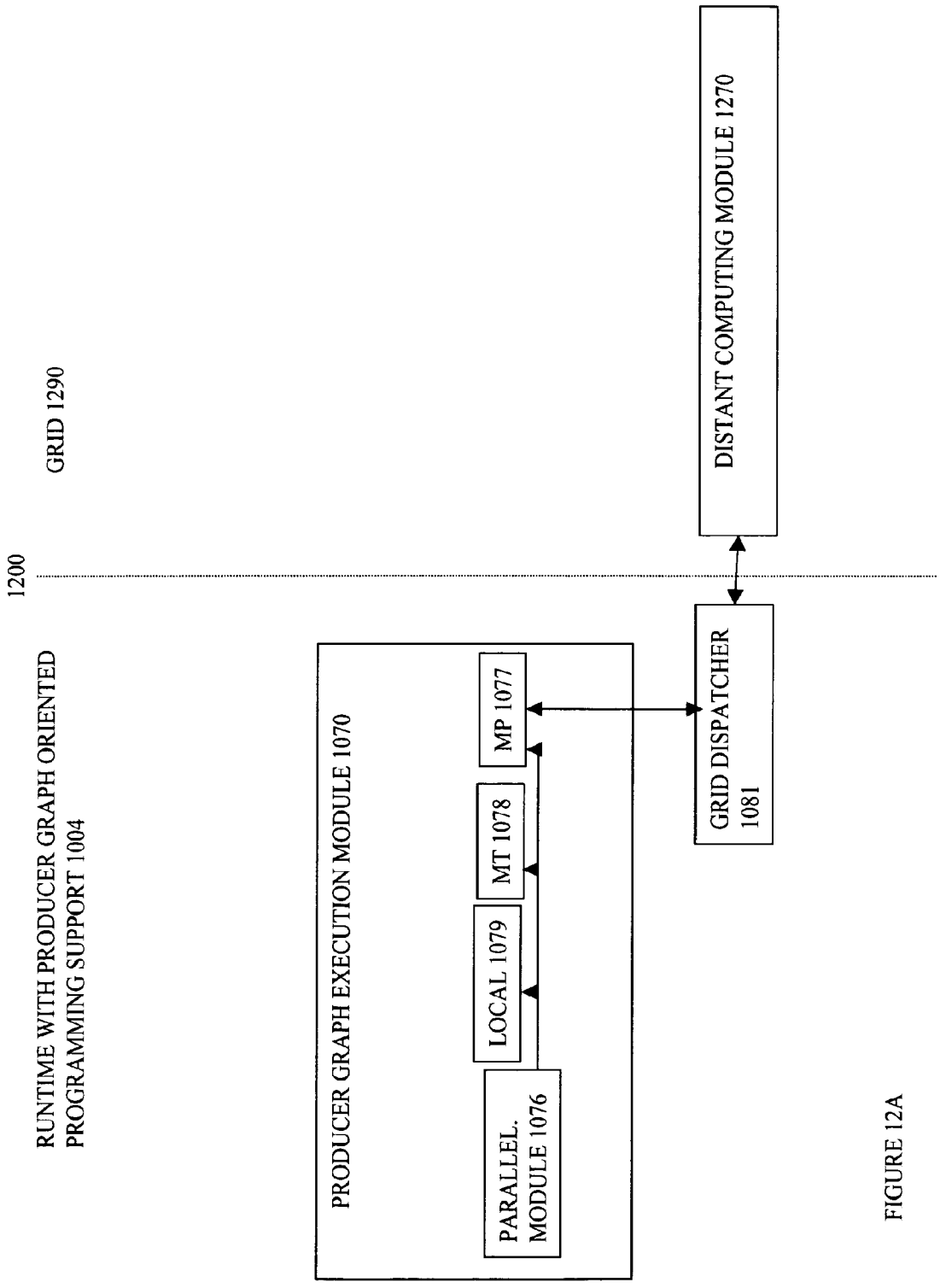

RUNTIME WITH PRODUCER GRAPH ORIENTED PROGRAMMING SUPPORT 1004
1200
GRID 1290
PRODUCER GRAPH EXECUTION MODULE 1070
PARALLEL. MODULE 1076
LOCAL 1079
MT 1078
MP 1077
GRID DISPATCHER 1081
DISTANT COMPUTING MODULE 1270

FIGURE 12A

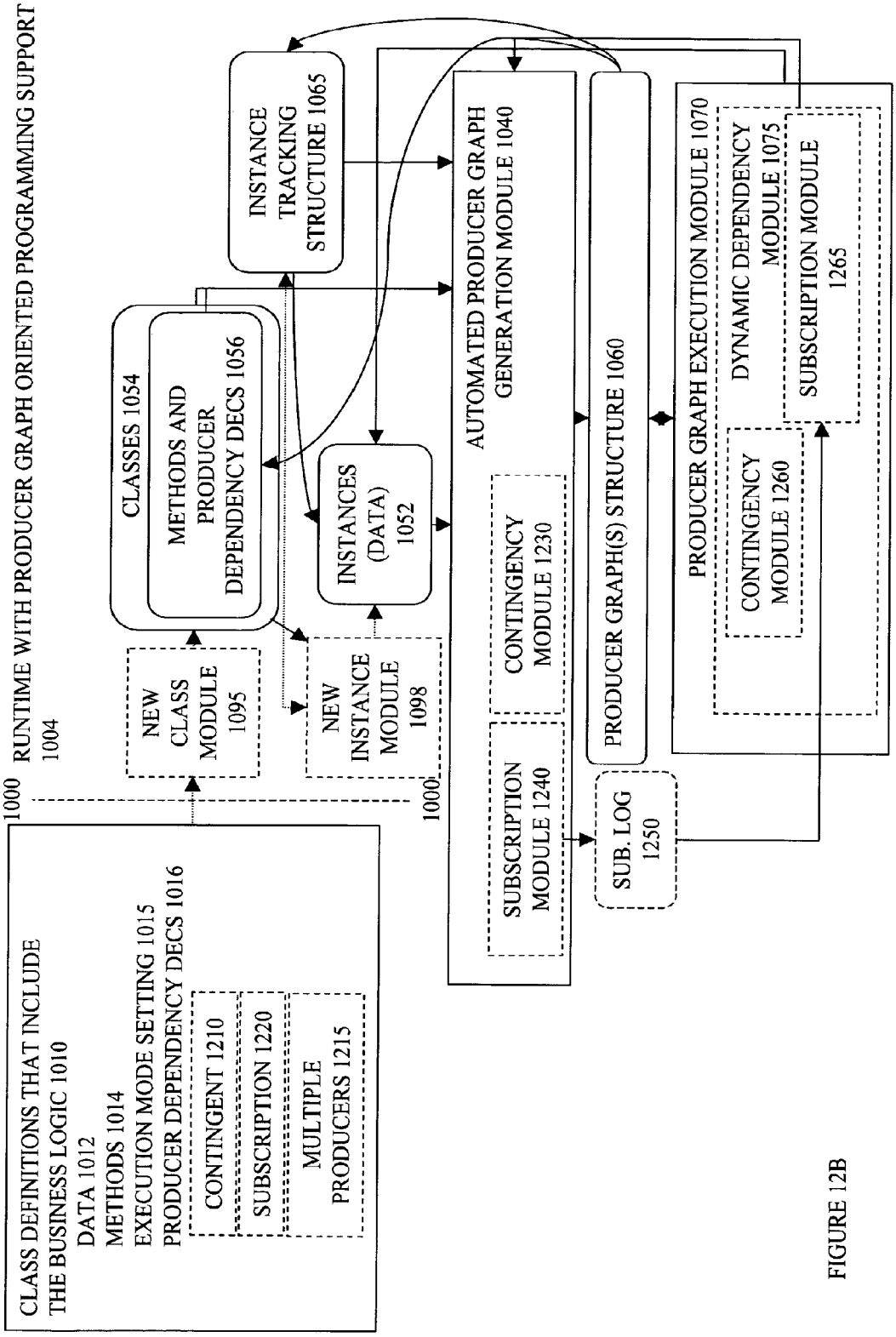

CLASS DEFINITIONS THAT INCLUDE THE BUSINESS LOGIC 1010
DATA 1012
METHODS 1014
EXECUTION MODE SETTING 1015
PRODUCER DEPENDENCY DECS 1016
CONTINGENT 1210
SUBSCRIPTION 1220
MULTIPLE PRODUCERS 1215
1000
RUNTIME WITH PRODUCER GRAPH ORIENTED PROGRAMMING SUPPORT 1004
NEW CLASS MODULE 1095
CLASSES 1054
METHODS AND PRODUCER DEPENDENCY DECS 1056
NEW INSTANCE MODULE 1098
INSTANCES (DATA) 1052
INSTANCE TRACKING STRUCTURE 1065
AUTOMATED PRODUCER GRAPH GENERATION MODULE 1040
CONTINGENCY MODULE 1230
SUBSCRIPTION MODULE 1240
SUB. LOG 1250
PRODUCER GRAPH(S) STRUCTURE 1060
PRODUCER GRAPH EXECUTION MODULE 1070
DYNAMIC DEPENDENCY MODULE 1075
CONTINGENCY MODULE 1260
SUBSCRIPTION MODULE 1265

FIGURE 12B

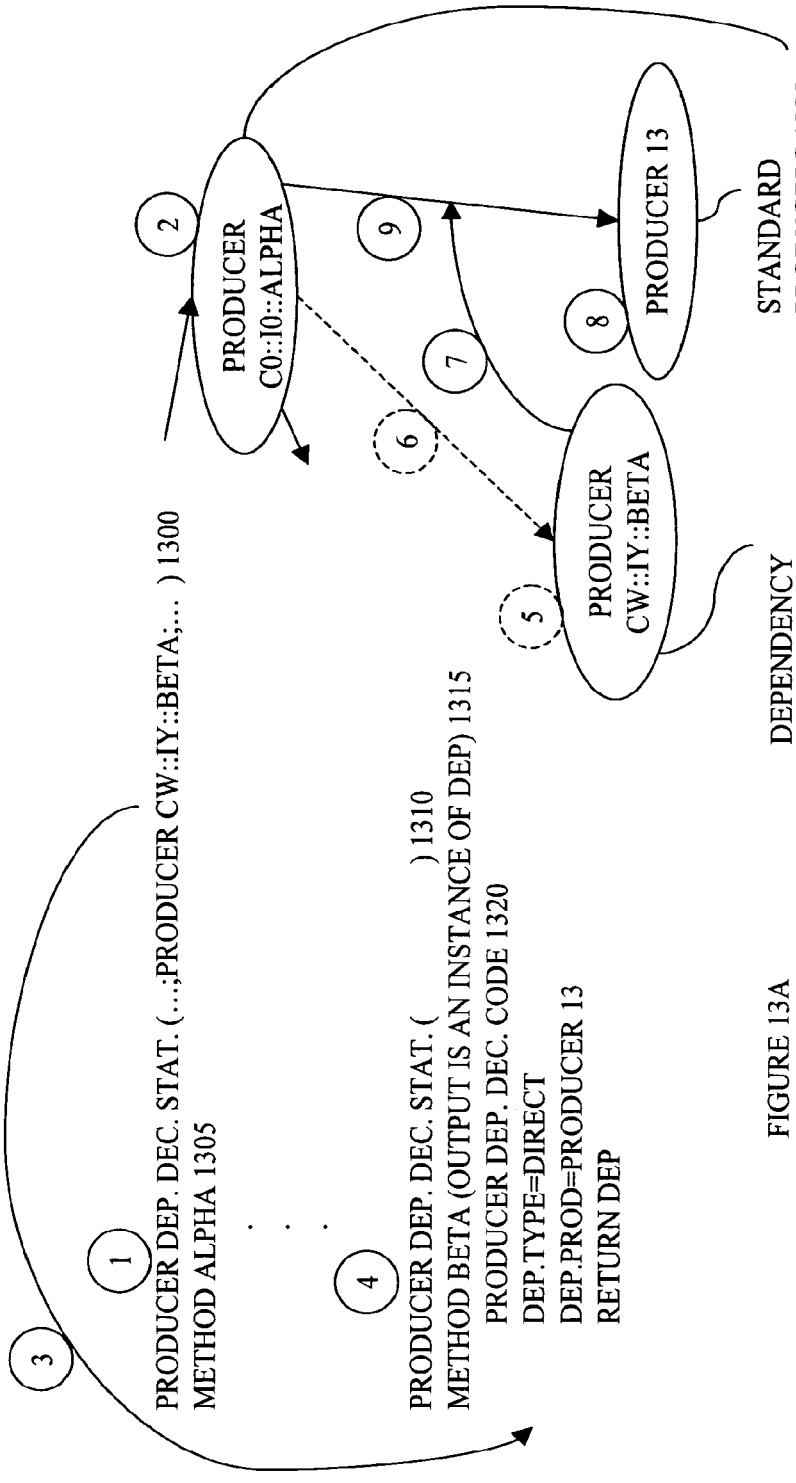
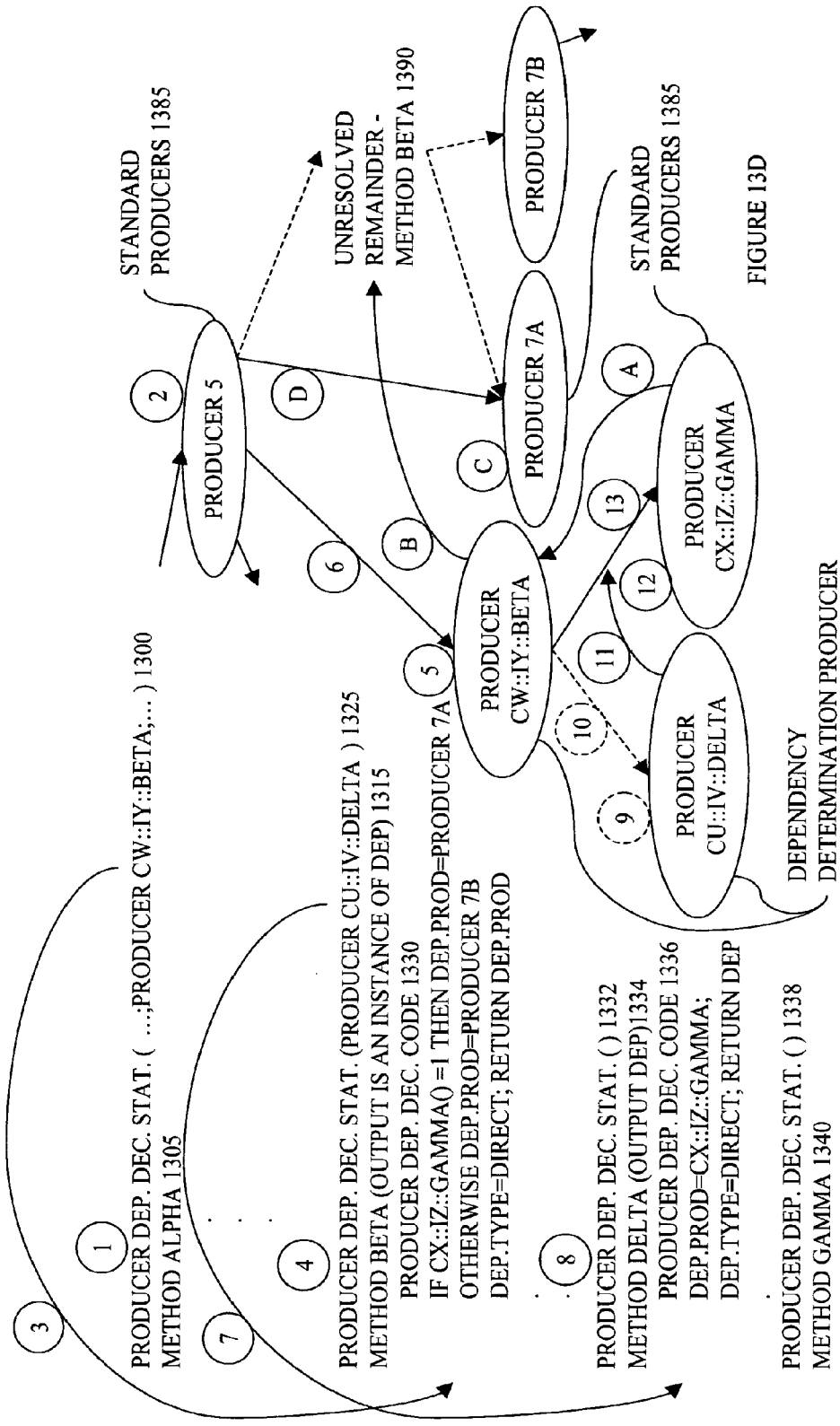


FIGURE 13A

FIGURE 13B


PRODUCER DEP. DEC. STAT. (...,PRODUCER CW::IY::BETA,...) 1300
METHOD ALPHA 1305
PRODUCER DEP. DEC. STAT. (PRODUCER CU::IV::DELTA) 1325
METHOD BETA (OUTPUT IS AN INSTANCE OF DEP) 1315
PRODUCER DEP. DEC. CODE 1330
IF CX::IZ::GAMMA() =1 THEN DEP.PROD=PRODUCER 7A
OTHERWISE DEP.PROD=PRODUCER 7B
DEP.TYPE=DIRECT; RETURN DEP.PROD
PRODUCER DEP. DEC. STAT. ( ) 1332
METHOD DELTA (OUTPUT DEP)1334
PRODUCER DEP. DEC. CODE 1336
DEP.PROD=CX::IZ::GAMMA;
DEP.TYPE=DIRECT; RETURN DEP
PRODUCER DEP. DEC. STAT. ( ) 1338
METHOD GAMMA 1340
RETURN X
FIGURE 13C
PRODUCER 5
PRODUCER CW::IY::BETA
PRODUCER CU::IV::DELTA
PRODUCER CX::IZ::GAMMA
PRODUCER 7A
PRODUCER 7B
STANDARD PRODUCERS 1385
UNRESOLVED REMAINDER - METHOD BETA 1390
STANDARD PRODUCERS 1385
DEPENDENCY DETERMINATION PRODUCER 1380
FIGURE 13D

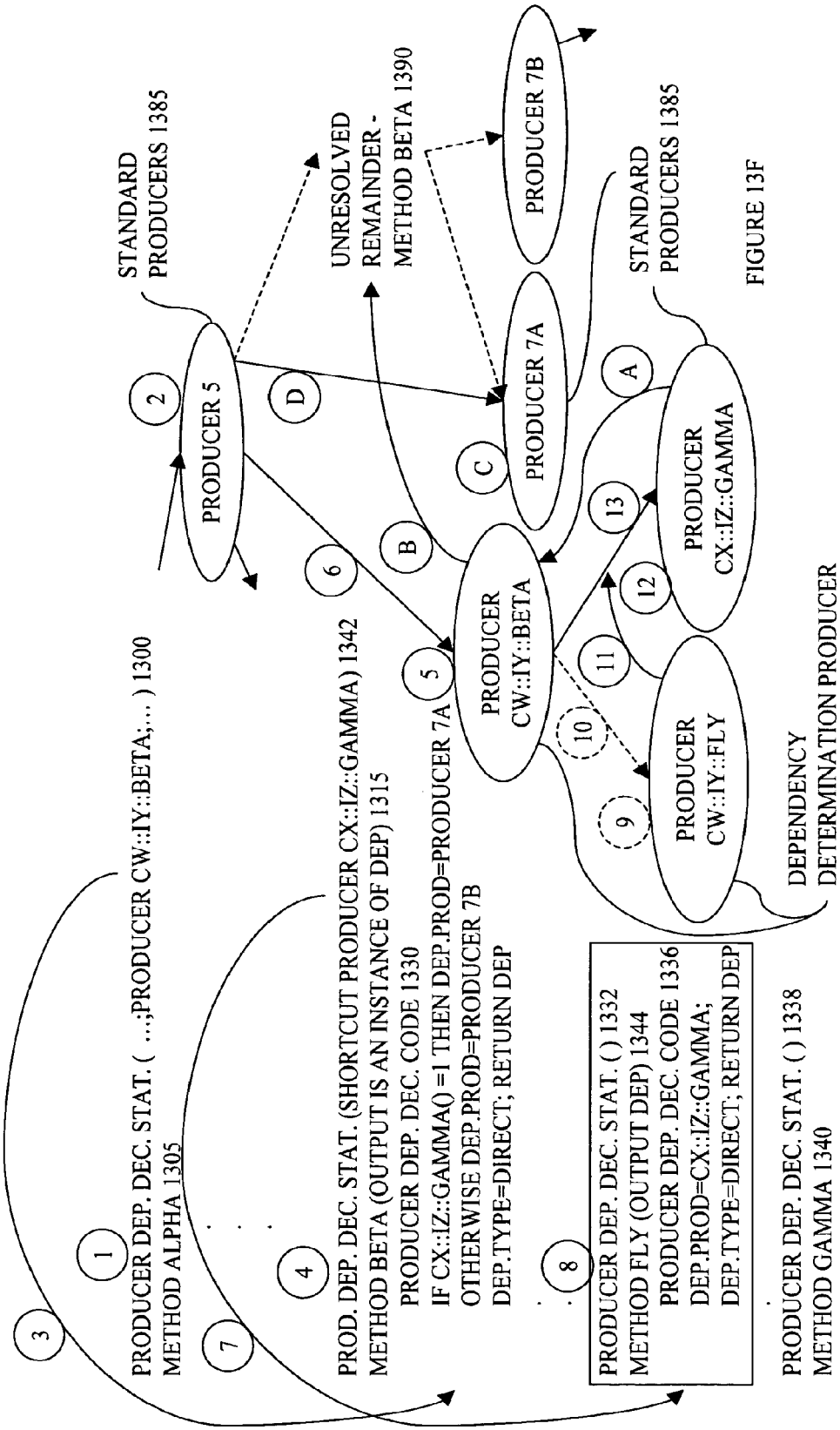


FIGURE 13E

FIGURE 13F

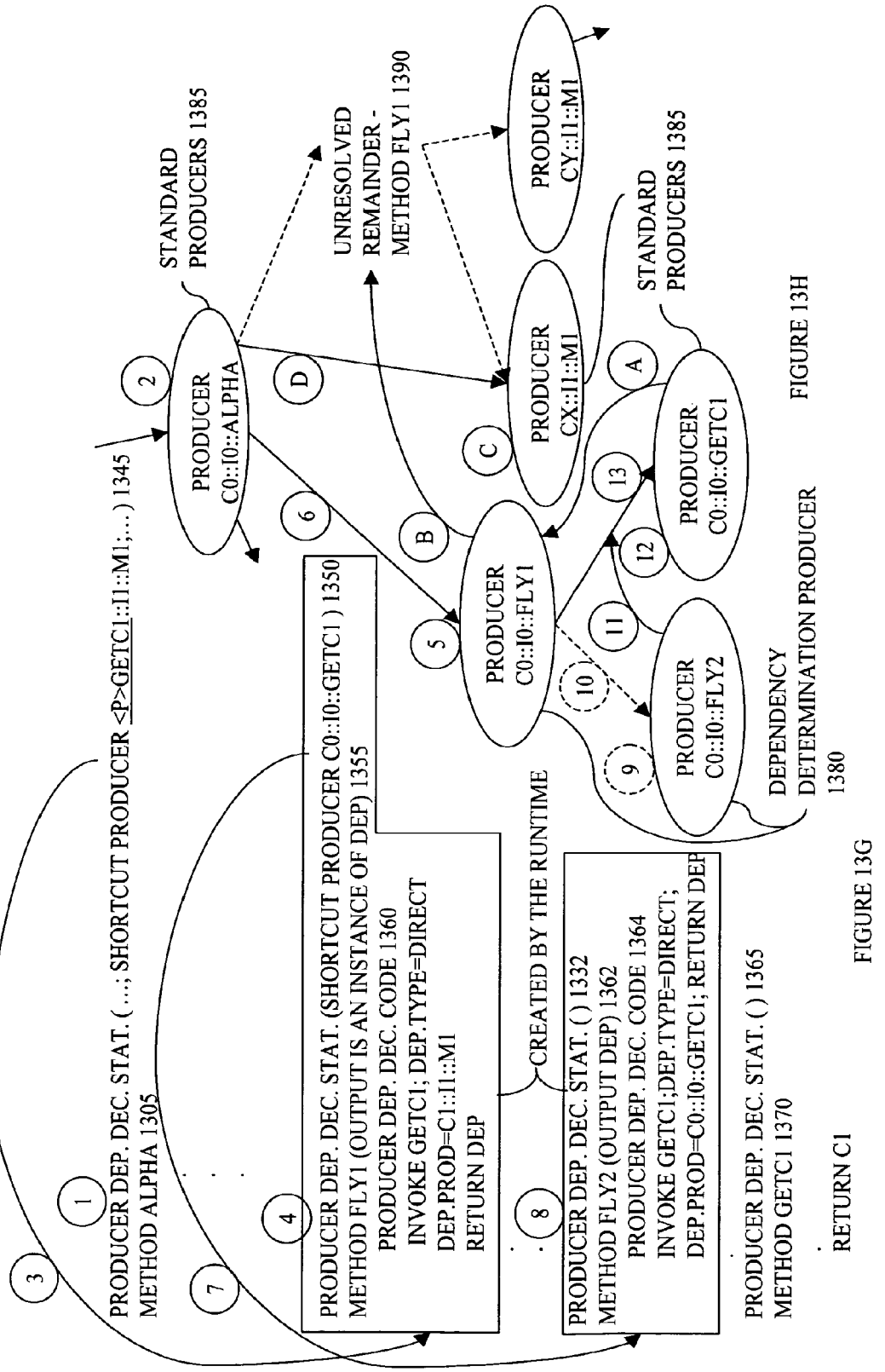


FIGURE 13G

FIGURE 13H

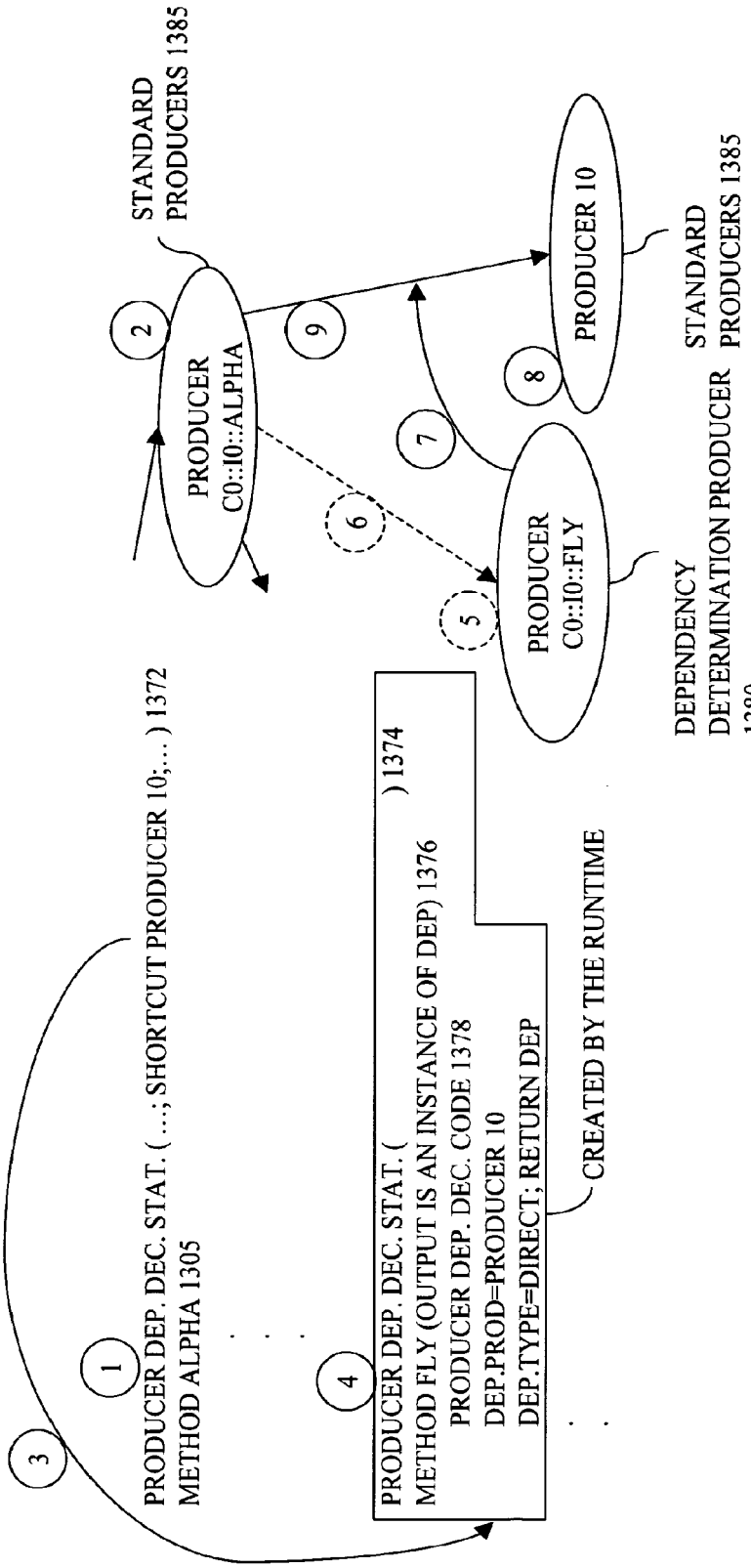


FIGURE 13J

FIGURE 13I

SUBSCRIBER'S PRODUCER KEY 1400	SUB. TYPE 1405	SUB. CRITERIA FOR TRIGGER PRODUCERS 1410	MATCHING PRODUCERS (ABSORBING) 1415	COMPLETED (ABSORBING) 1420	PARENT LINK MODE 1425	PARENT CLASS 1430	PARENT METHOD 1435	PARENT INSTANCE 1437	DEPENDENCY DET. PRODUCER REFERENCE 1421
1450	ABSORBING	FROM 1455	1460A..N	YES OR NO	LINK MODE OF 1450	N/A	N/A	N/A	1455
1470	STICKY	FROM 1470	N/A	N/A	LINK MODE OF 1480 FROM 1470	CLASS OF 1480 FROM 1470	METHOD OF 1480 FROM 1470	1480	1470

FIGURE 14A

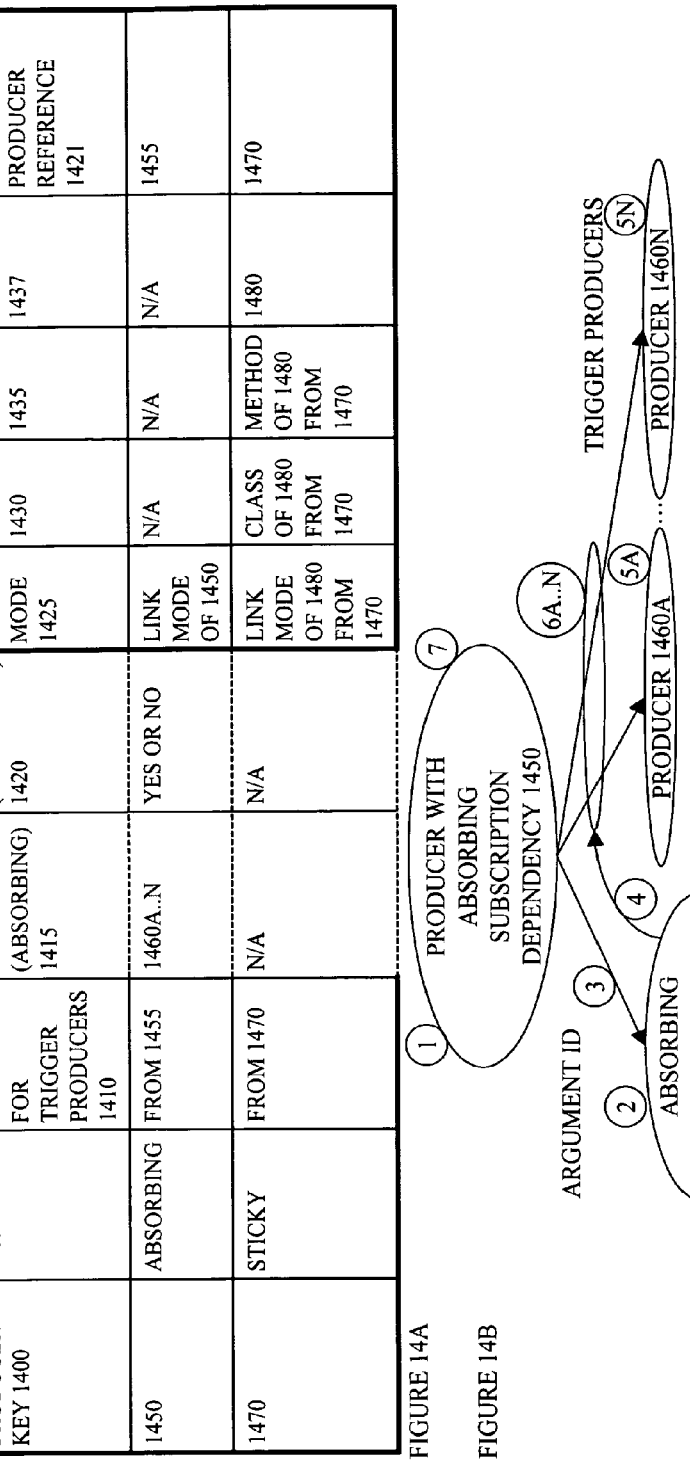


FIGURE 14B

FIGURE 14C

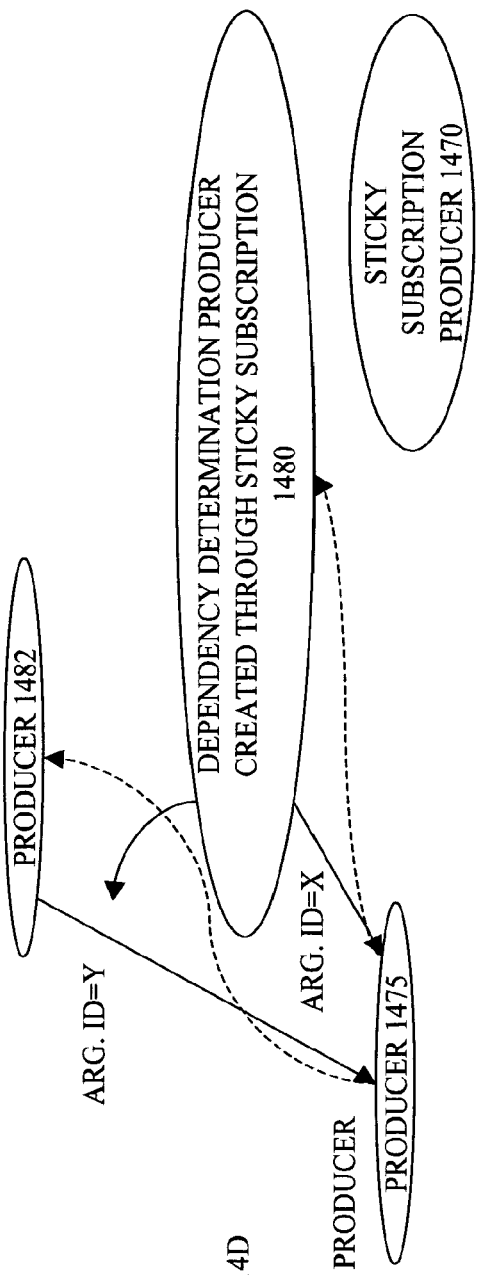


FIGURE 14D

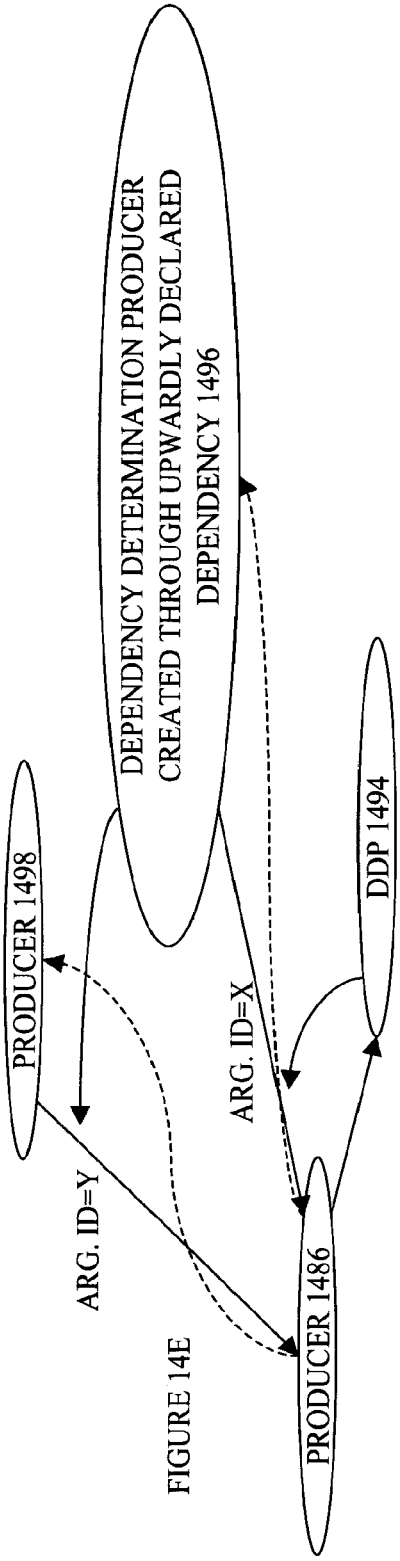


FIGURE 14E

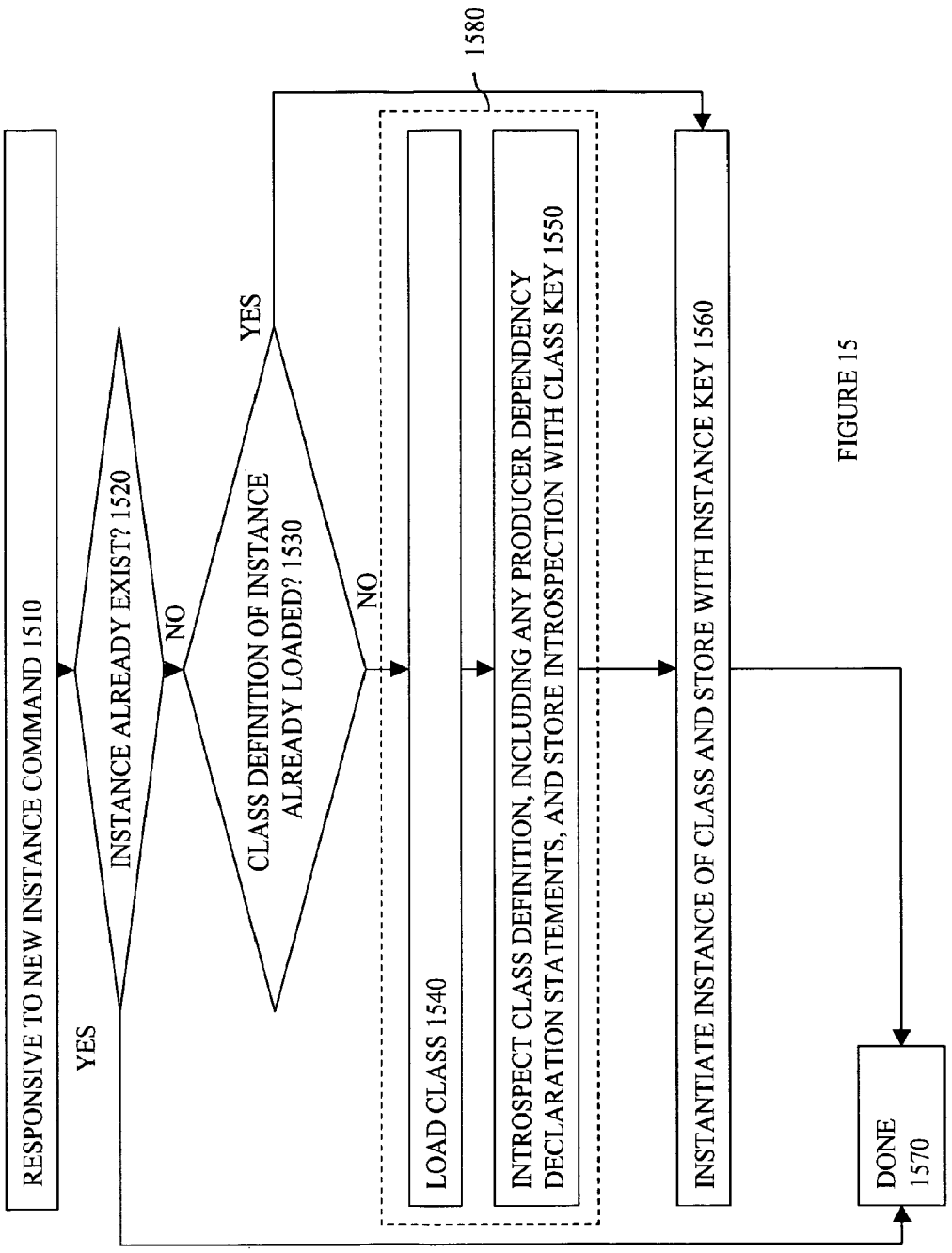
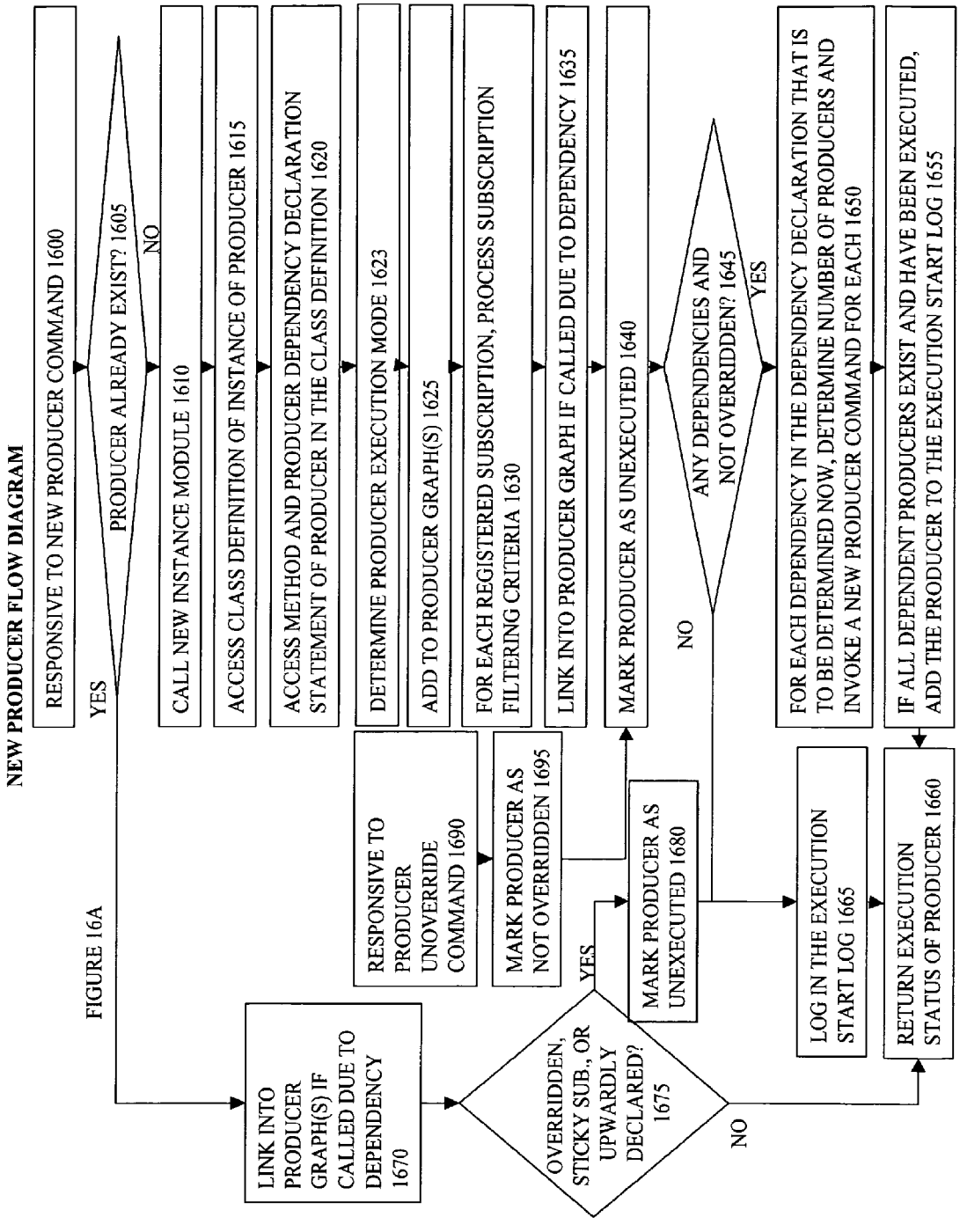

RESPONSIVE TO NEW INSTANCE COMMAND 1510
INSTANCE ALREADY EXIST? 1520
YES
NO
CLASS DEFINITION OF INSTANCE ALREADY LOADED? 1530
YES
NO
1580
LOAD CLASS 1540
INTROSPECT CLASS DEFINITION, INCLUDING ANY PRODUCER DEPENDENCY DECLARATION STATEMENTS, AND STORE INTROSPECTION WITH CLASS KEY 1550
INSTANTIATE INSTANCE OF CLASS AND STORE WITH INSTANCE KEY 1560
DONE 1570

FIGURE 15


NEW PRODUCER FLOW DIAGRAM
RESPONSIVE TO NEW PRODUCER COMMAND 1600
PRODUCER ALREADY EXIST? 1605
YES
NO
CALL NEW INSTANCE MODULE 1610
ACCESS CLASS DEFINITION OF INSTANCE OF PRODUCER 1615
ACCESS METHOD AND PRODUCER DEPENDENCY DECLARATION STATEMENT OF PRODUCER IN THE CLASS DEFINITION 1620
DETERMINE PRODUCER EXECUTION MODE 1623
ADD TO PRODUCER GRAPH(S) 1625
FOR EACH REGISTERED SUBSCRIPTION, PROCESS SUBSCRIPTION FILTERING CRITERIA 1630
LINK INTO PRODUCER GRAPH IF CALLED DUE TO DEPENDENCY 1635
MARK PRODUCER AS UNEXECUTED 1640
ANY DEPENDENCIES AND NOT OVERRIDDEN? 1645
YES
NO
FOR EACH DEPENDENCY IN THE DEPENDENCY DECLARATION THAT IS TO BE DETERMINED NOW, DETERMINE NUMBER OF PRODUCERS AND INVOKE A NEW PRODUCER COMMAND FOR EACH 1650
IF ALL DEPENDENT PRODUCERS EXIST AND HAVE BEEN EXECUTED, ADD THE PRODUCER TO THE EXECUTION START LOG 1655
RETURN EXECUTION STATUS OF PRODUCER 1660
LOG IN THE EXECUTION START LOG 1665
MARK PRODUCER AS UNEXECUTED 1680
OVERRIDDEN, STICKY SUB., OR UPWARDLY DECLARED? 1675
YES
NO
LINK INTO PRODUCER GRAPH(S) IF CALLED DUE TO DEPENDENCY 1670
RESPONSIVE TO PRODUCER UNOVERRIDE COMMAND 1690
MARK PRODUCER AS NOT OVERRIDDEN 1695
FIGURE 16A

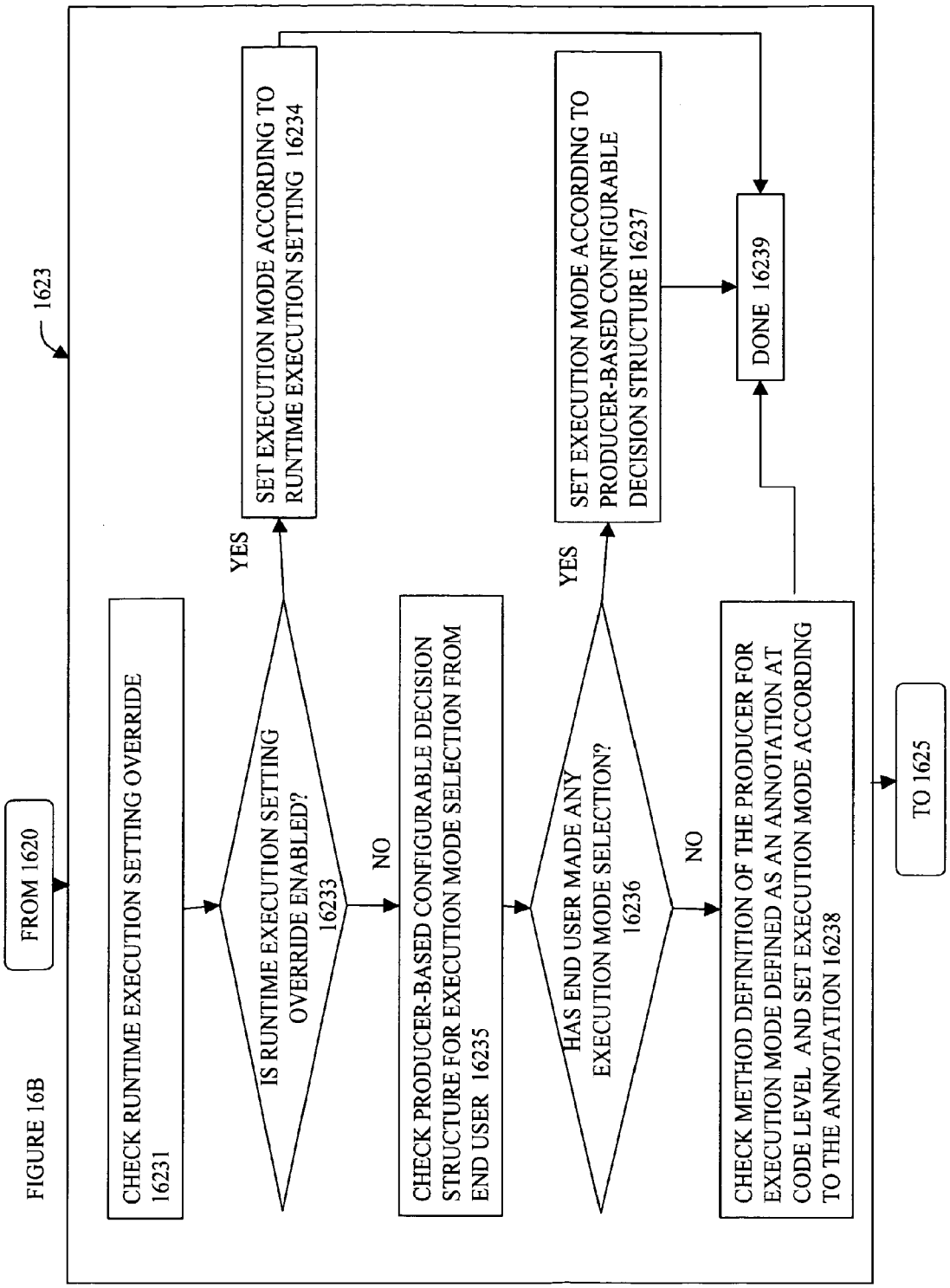

1623
FROM 1620
CHECK RUNTIME EXECUTION SETTING OVERRIDE 16231
IS RUNTIME EXECUTION SETTING OVERRIDE ENABLED? 16233
YES
SET EXECUTION MODE ACCORDING TO RUNTIME EXECUTION SETTING 16234
NO
CHECK PRODUCER-BASED CONFIGURABLE DECISION STRUCTURE FOR EXECUTION MODE SELECTION FROM END USER 16235
HAS END USER MADE ANY EXECUTION MODE SELECTION? 16236
YES
SET EXECUTION MODE ACCORDING TO PRODUCER-BASED CONFIGURABLE DECISION STRUCTURE 16237
NO
CHECK METHOD DEFINITION OF THE PRODUCER FOR EXECUTION MODE DEFINED AS AN ANNOTATION AT CODE LEVEL AND SET EXECUTION MODE ACCORDING TO THE ANNOTATION 16238
DONE 16239
TO 1625

FIGURE 16B

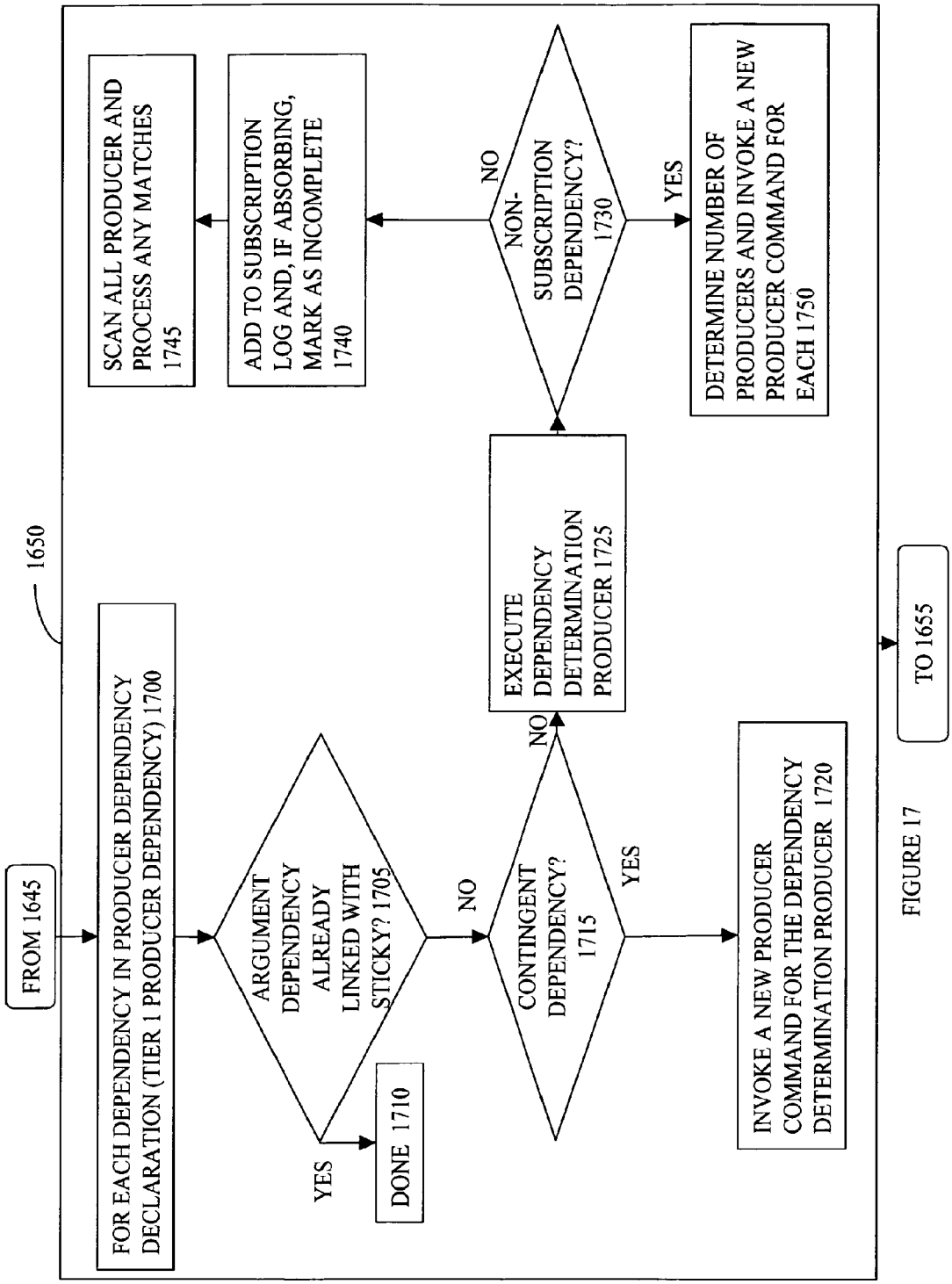

1650
FROM 1645
FOR EACH DEPENDENCY IN PRODUCER DEPENDENCY DECLARATION (TIER 1 PRODUCER DEPENDENCY) 1700
ARGUMENT DEPENDENCY ALREADY LINKED WITH STICKY? 1705
YES
DONE 1710
NO
CONTINGENT DEPENDENCY? 1715
YES
INVOKE A NEW PRODUCER COMMAND FOR THE DEPENDENCY DETERMINATION PRODUCER 1720
NO
EXECUTE DEPENDENCY DETERMINATION PRODUCER 1725
NON-SUBSCRIPTION DEPENDENCY? 1730
NO
YES
ADD TO SUBSCRIPTION LOG AND, IF ABSORBING, MARK AS INCOMPLETE 1740
SCAN ALL PRODUCER AND PROCESS ANY MATCHES 1745
DETERMINE NUMBER OF PRODUCERS AND INVOKE A NEW PRODUCER COMMAND FOR EACH 1750
TO 1655

FIGURE 17

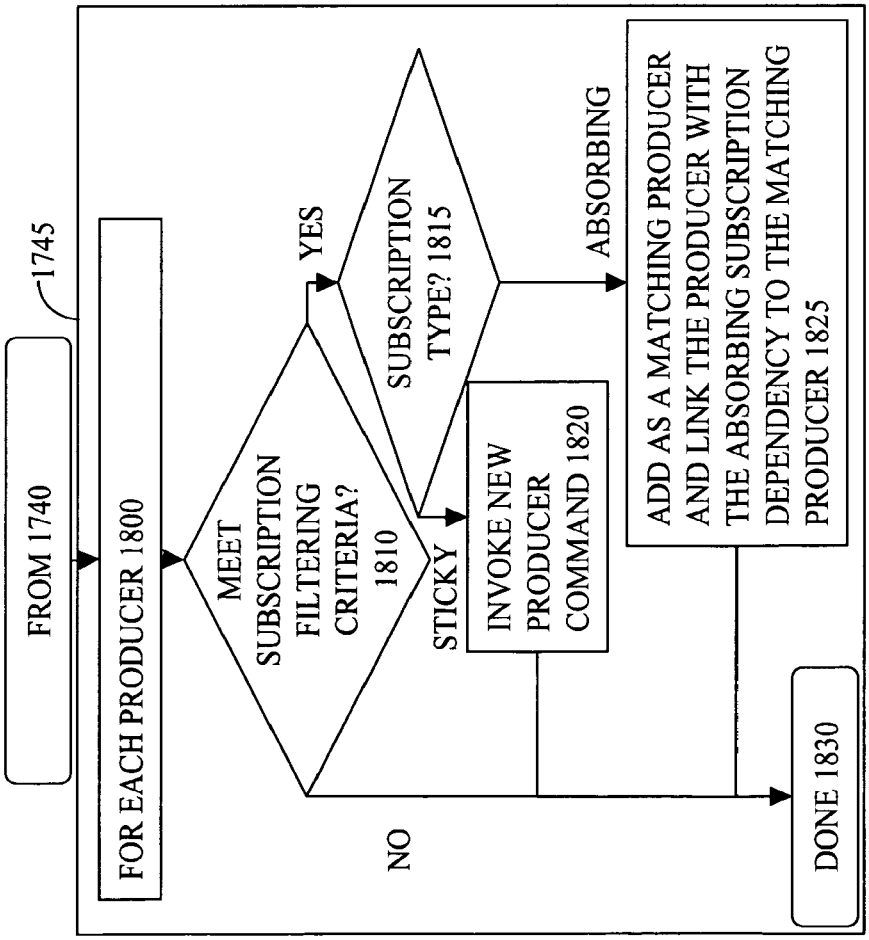
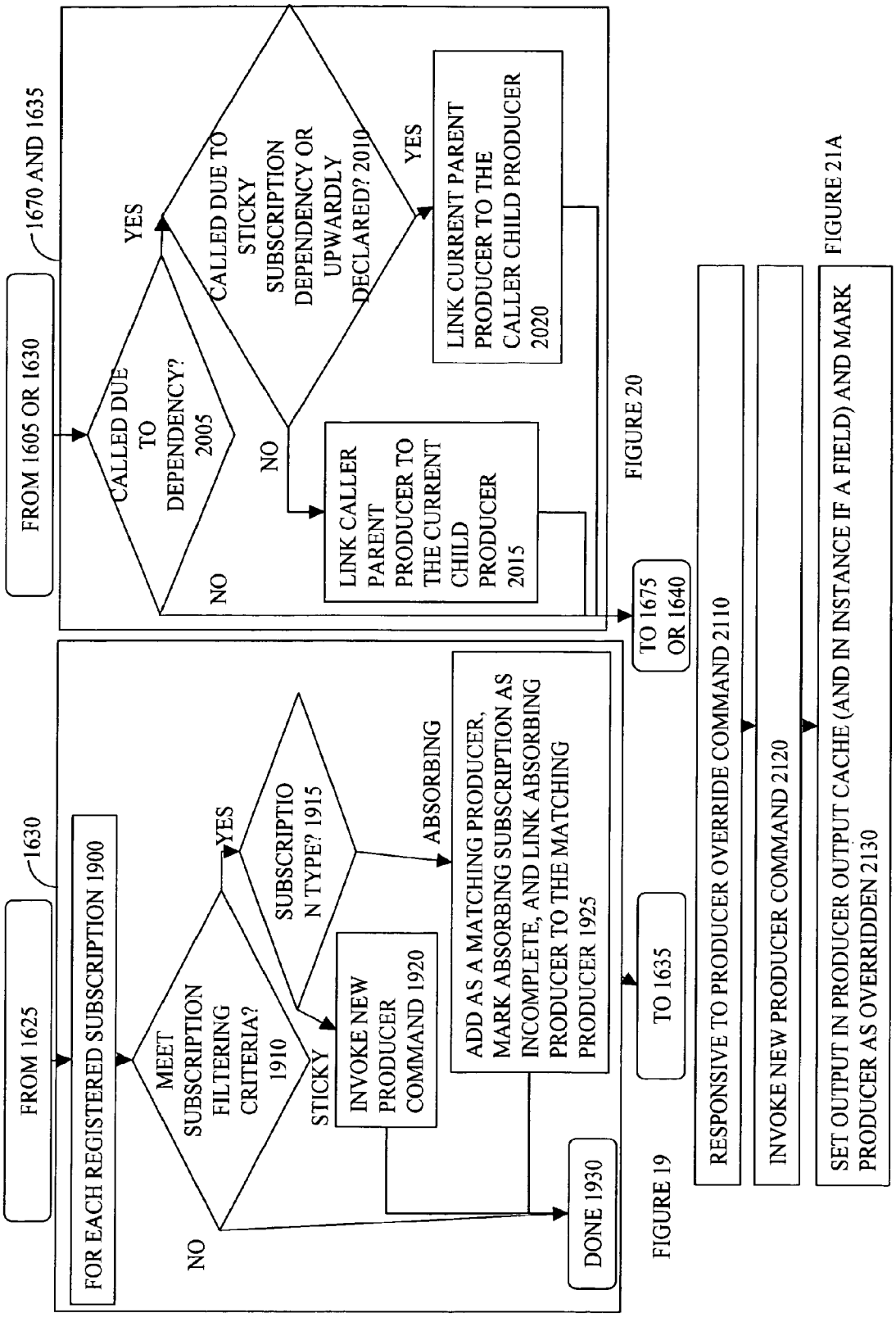
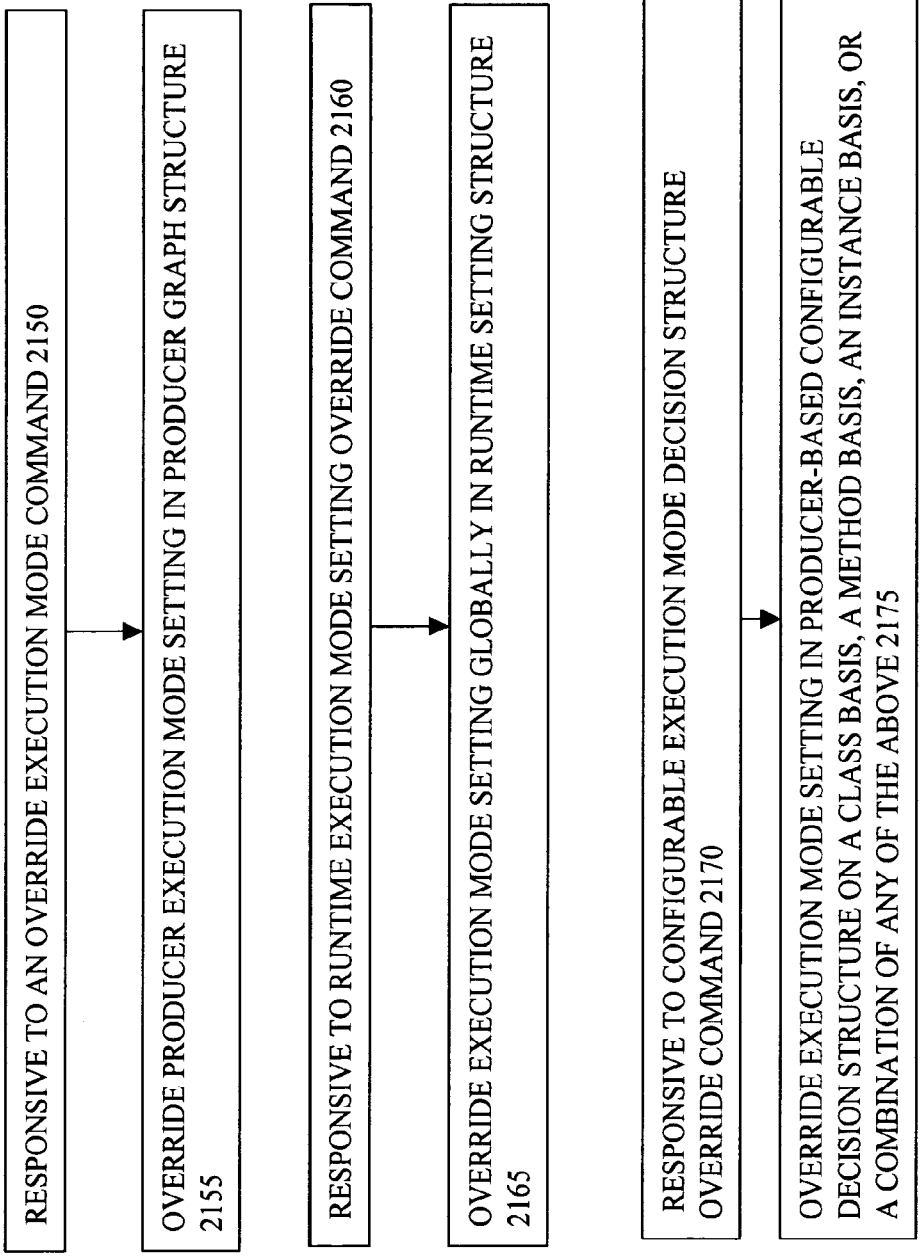

FROM 1740
1745
FOR EACH PRODUCER 1800
MEET SUBSCRIPTION FILTERING CRITERIA? 1810
YES
SUBSCRIPTION TYPE? 1815
ABSORBING
STICKY
INVOKE NEW PRODUCER COMMAND 1820
ADD AS A MATCHING PRODUCER AND LINK THE PRODUCER WITH THE ABSORBING SUBSCRIPTION DEPENDENCY TO THE MATCHING PRODUCER 1825
NO
DONE 1830

FIGURE 18


FROM 1625
1630
FOR EACH REGISTERED SUBSCRIPTION 1900
MEET SUBSCRIPTION FILTERING CRITERIA? 1910
NO
YES
SUBSCRIPTIO N TYPE? 1915
STICKY
INVOKE NEW PRODUCER COMMAND 1920
ABSORBING
ADD AS A MATCHING PRODUCER, MARK ABSORBING SUBSCRIPTION AS INCOMPLETE, AND LINK ABSORBING PRODUCER TO THE MATCHING PRODUCER 1925
DONE 1930
TO 1635
FIGURE 19
FROM 1605 OR 1630
1670 AND 1635
CALLED DUE TO DEPENDENCY? 2005
NO
YES
CALLED DUE TO STICKY SUBSCRIPTION DEPENDENCY OR UPWARDLY DECLARED? 2010
NO
YES
LINK CALLER PARENT PRODUCER TO THE CURRENT CHILD PRODUCER 2015
LINK CURRENT PARENT PRODUCER TO THE CALLER CHILD PRODUCER 2020
TO 1675 OR 1640
FIGURE 20
RESPONSIVE TO PRODUCER OVERRIDE COMMAND 2110
INVOKE NEW PRODUCER COMMAND 2120
SET OUTPUT IN PRODUCER OUTPUT CACHE (AND IN INSTANCE IF A FIELD) AND MARK PRODUCER AS OVERRIDDEN 2130
FIGURE 21A


RESPONSIVE TO AN OVERRIDE EXECUTION MODE COMMAND 2150
OVERRIDE PRODUCER EXECUTION MODE SETTING IN PRODUCER GRAPH STRUCTURE 2155
FIGURE 21B
RESPONSIVE TO RUNTIME EXECUTION MODE SETTING OVERRIDE COMMAND 2160
OVERRIDE EXECUTION MODE SETTING GLOBALLY IN RUNTIME SETTING STRUCTURE 2165
FIGURE 21C
RESPONSIVE TO CONFIGURABLE EXECUTION MODE DECISION STRUCTURE OVERRIDE COMMAND 2170
OVERRIDE EXECUTION MODE SETTING IN PRODUCER-BASED CONFIGURABLE DECISION STRUCTURE ON A CLASS BASIS, A METHOD BASIS, AN INSTANCE BASIS, OR A COMBINATION OF ANY OF THE ABOVE 2175
FIGURE 21D

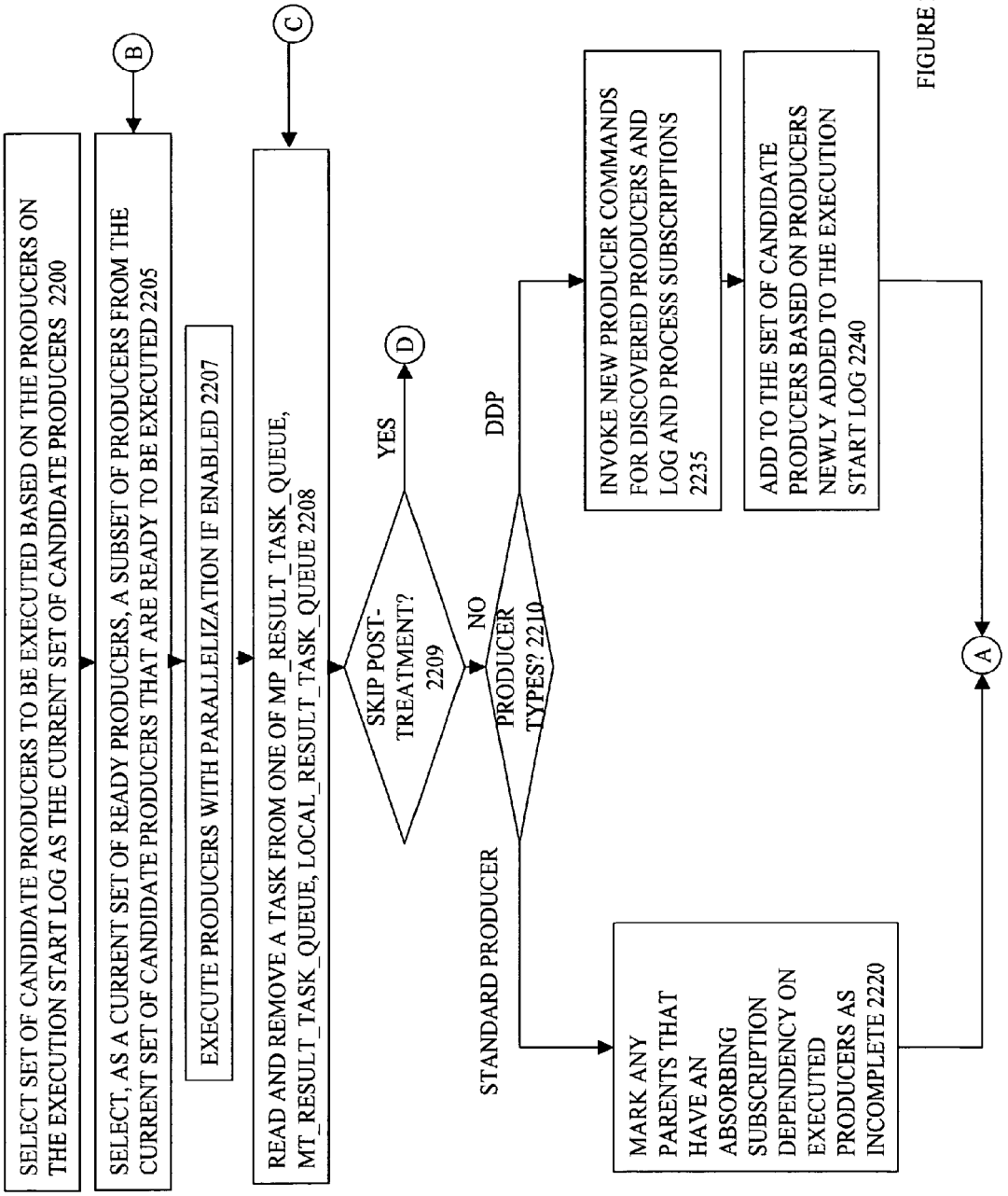

SELECT SET OF CANDIDATE PRODUCERS TO BE EXECUTED BASED ON THE PRODUCERS ON THE EXECUTION START LOG AS THE CURRENT SET OF CANDIDATE PRODUCERS 2200
B
SELECT, AS A CURRENT SET OF READY PRODUCERS, A SUBSET OF PRODUCERS FROM THE CURRENT SET OF CANDIDATE PRODUCERS THAT ARE READY TO BE EXECUTED 2205
EXECUTE PRODUCERS WITH PARALLELIZATION IF ENABLED 2207
C
READ AND REMOVE A TASK FROM ONE OF MP_RESULT_TASK_QUEUE, MT_RESULT_TASK_QUEUE, LOCAL_RESULT_TASK_QUEUE 2208
SKIP POST-TREATMENT? 2209
YES
D
NO
PRODUCER TYPES? 2210
STANDARD PRODUCER
DDP
MARK ANY PARENTS THAT HAVE AN ABSORBING SUBSCRIPTION DEPENDENCY ON EXECUTED PRODUCERS AS INCOMPLETE 2220
INVOKE NEW PRODUCER COMMANDS FOR DISCOVERED PRODUCERS AND LOG AND PROCESS SUBSCRIPTIONS 2235
ADD TO THE SET OF CANDIDATE PRODUCERS BASED ON PRODUCERS NEWLY ADDED TO THE EXECUTION START LOG 2240
A

FIGURE 22A

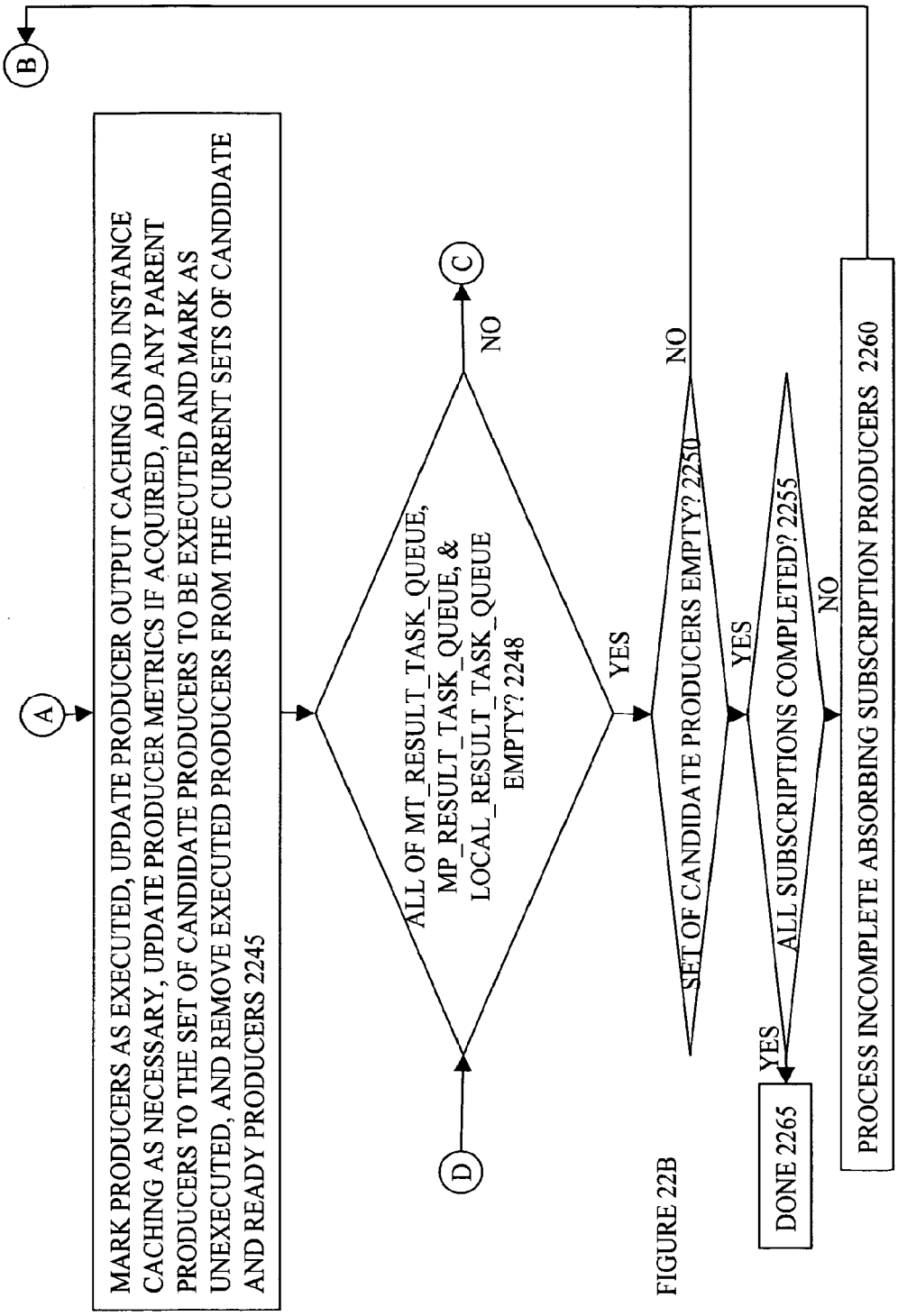

A
MARK PRODUCERS AS EXECUTED, UPDATE PRODUCER OUTPUT CACHING AND INSTANCE CACHING AS NECESSARY, UPDATE PRODUCER METRICS IF ACQUIRED, ADD ANY PARENT PRODUCERS TO THE SET OF CANDIDATE PRODUCERS TO BE EXECUTED AND MARK AS UNEXECUTED, AND REMOVE EXECUTED PRODUCERS FROM THE CURRENT SETS OF CANDIDATE AND READY PRODUCERS 2245
ALL OF MT_RESULT_TASK_QUEUE, MP_RESULT_TASK_QUEUE, & LOCAL_RESULT_TASK_QUEUE EMPTY? 2248
NO
C
D
YES
SET OF CANDIDATE PRODUCERS EMPTY? 2250
NO
YES
ALL SUBSCRIPTIONS COMPLETED? 2255
NO
YES
DONE 2265
PROCESS INCOMPLETE ABSORBING SUBSCRIPTION PRODUCERS 2260
B

FIGURE 22B

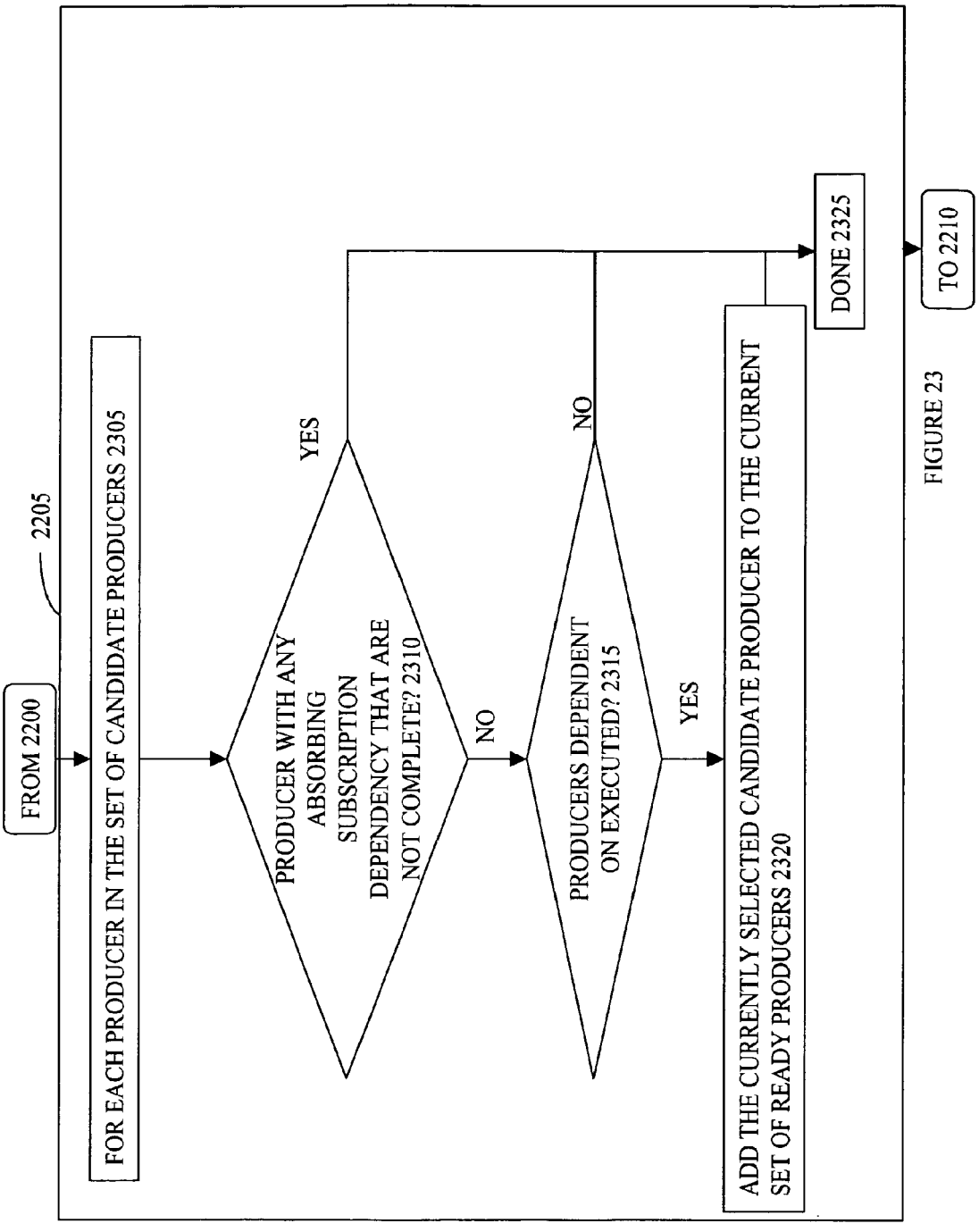

FROM 2200
2205
FOR EACH PRODUCER IN THE SET OF CANDIDATE PRODUCERS 2305
PRODUCER WITH ANY ABSORBING SUBSCRIPTION DEPENDENCY THAT ARE NOT COMPLETE? 2310
YES
NO
PRODUCERS DEPENDENT ON EXECUTED? 2315
NO
YES
ADD THE CURRENTLY SELECTED CANDIDATE PRODUCER TO THE CURRENT SET OF READY PRODUCERS 2320
DONE 2325
TO 2210

FIGURE 23

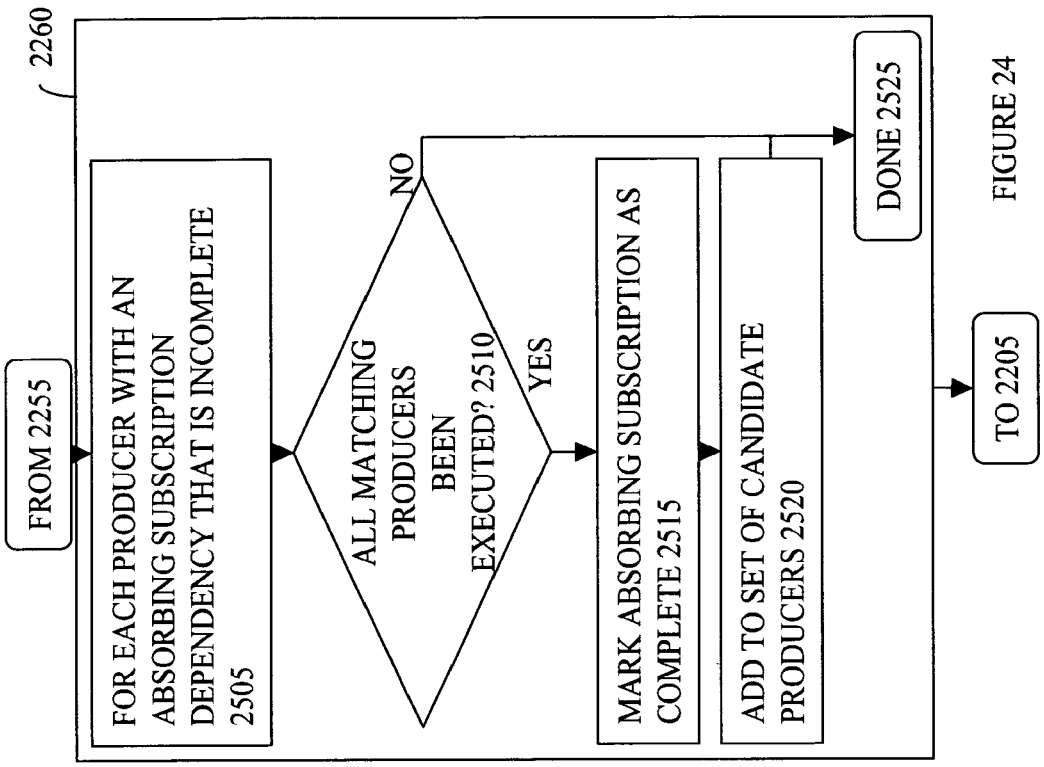

2260
FROM 2255
FOR EACH PRODUCER WITH AN ABSORBING SUBSCRIPTION DEPENDENCY THAT IS INCOMPLETE 2505
ALL MATCHING PRODUCERS BEEN EXECUTED? 2510
NO
YES
MARK ABSORBING SUBSCRIPTION AS COMPLETE 2515
ADD TO SET OF CANDIDATE PRODUCERS 2520
DONE 2525
TO 2205

FIGURE 24

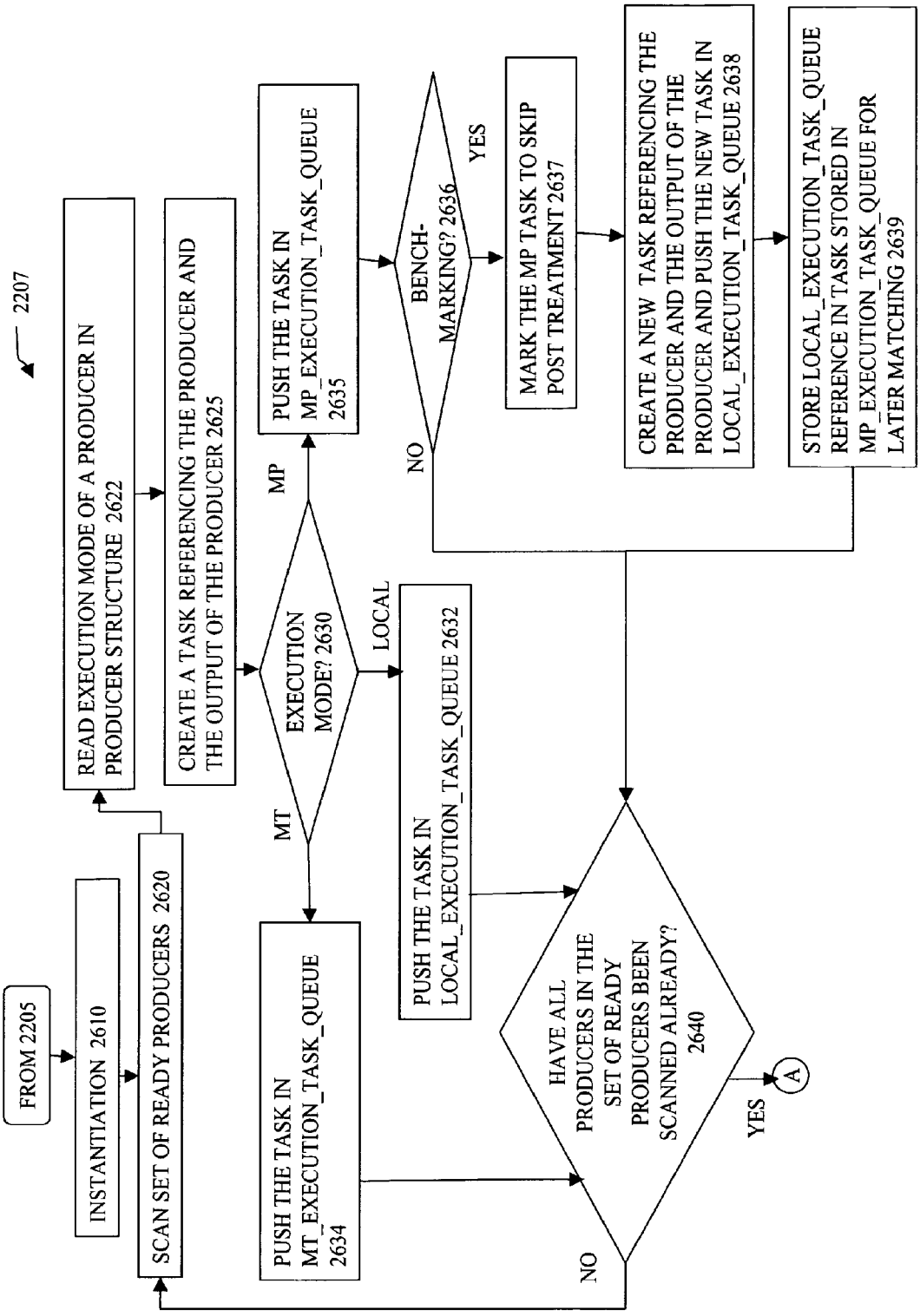

2207
FROM 2205
INSTANTIATION 2610
SCAN SET OF READY PRODUCERS 2620
READ EXECUTION MODE OF A PRODUCER IN PRODUCER STRUCTURE 2622
CREATE A TASK REFERENCING THE PRODUCER AND THE OUTPUT OF THE PRODUCER 2625
EXECUTION MODE? 2630
MT
MP
LOCAL
PUSH THE TASK IN MT_EXECUTION_TASK_QUEUE 2634
PUSH THE TASK IN MP_EXECUTION_TASK_QUEUE 2635
PUSH THE TASK IN LOCAL_EXECUTION_TASK_QUEUE 2632
BENCH-MARKING? 2636
YES
NO
MARK THE MP TASK TO SKIP POST TREATMENT 2637
CREATE A NEW TASK REFERENCING THE PRODUCER AND THE OUTPUT OF THE PRODUCER AND PUSH THE NEW TASK IN LOCAL_EXECUTION_TASK_QUEUE 2638
STORE LOCAL_EXECUTION_TASK_QUEUE REFERENCE IN TASK STORED IN MP_EXECUTION_TASK_QUEUE FOR LATER MATCHING 2639
HAVE ALL PRODUCERS IN THE SET OF READY PRODUCERS BEEN SCANNED ALREADY? 2640
NO
YES
A

FIGURE 25

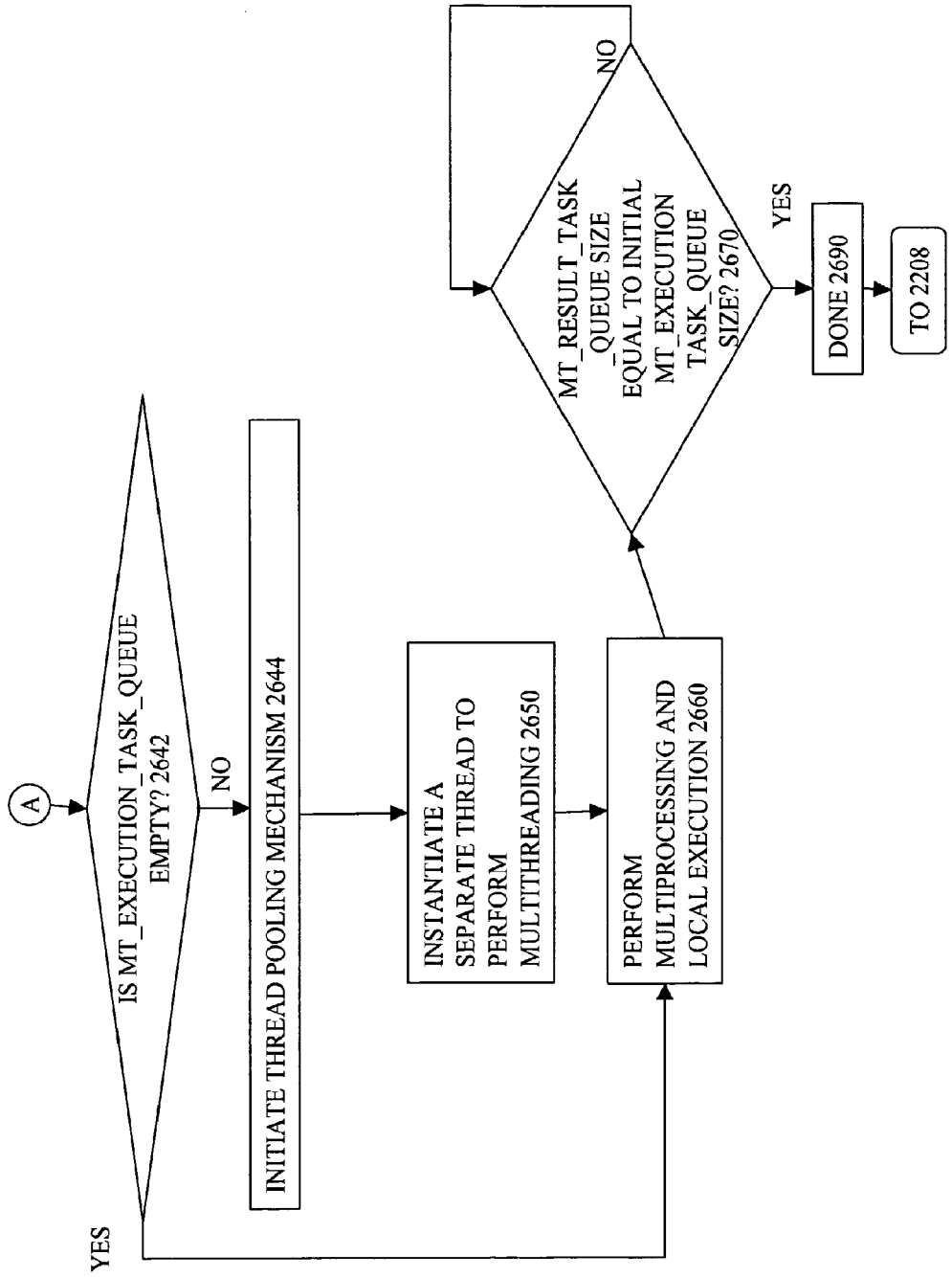

A
IS MT_EXECUTION_TASK_QUEUE EMPTY? 2642
NO
YES
INITIATE THREAD POOLING MECHANISM 2644
INSTANTIATE A SEPARATE THREAD TO PERFORM MULTITHREADING 2650
PERFORM MULTIPROCESSING AND LOCAL EXECUTION 2660
MT_RESULT_TASK _QUEUE SIZE EQUAL TO INITIAL MT_EXECUTION TASK_QUEUE SIZE? 2670
NO
YES
DONE 2690
TO 2208

FIGURE 26

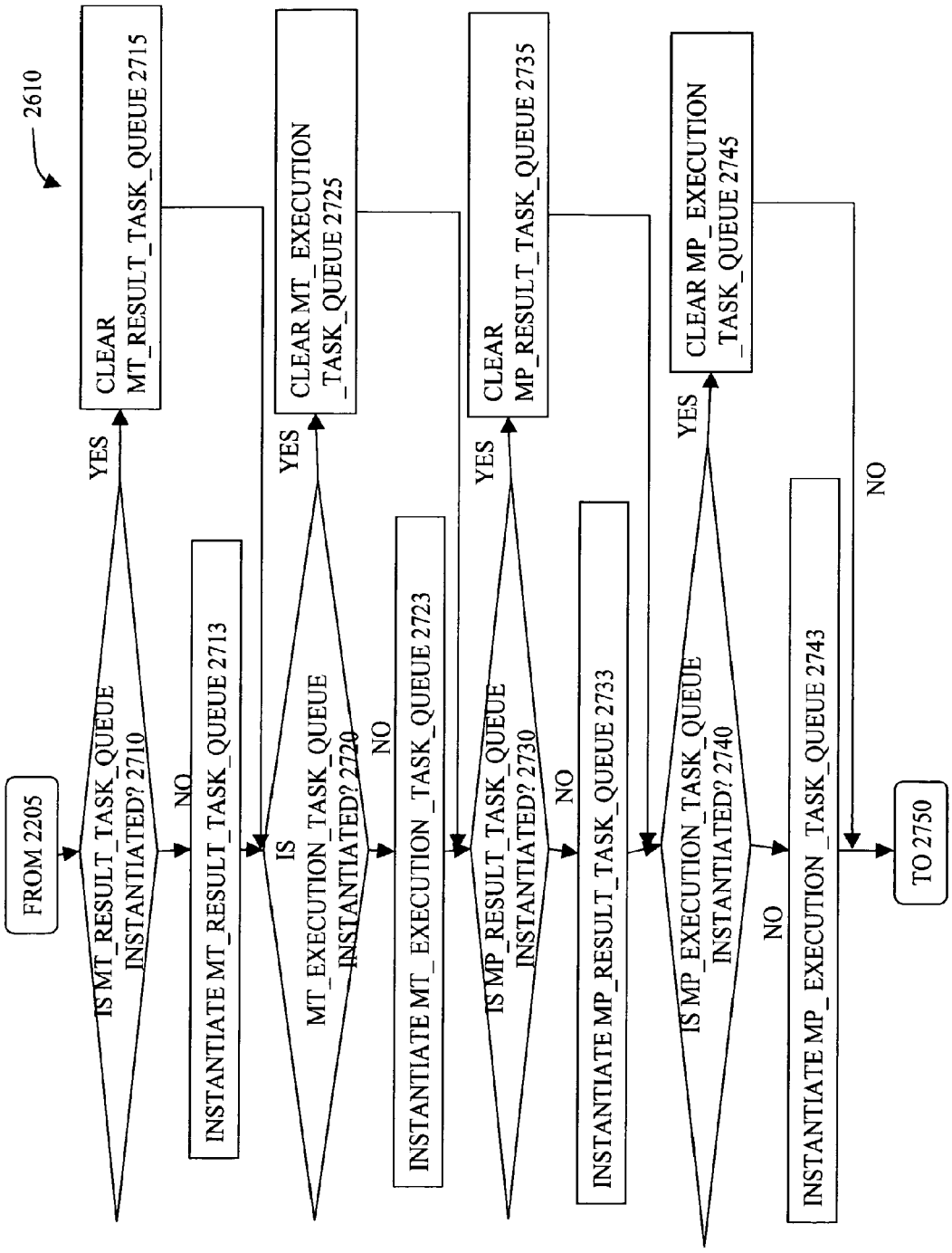
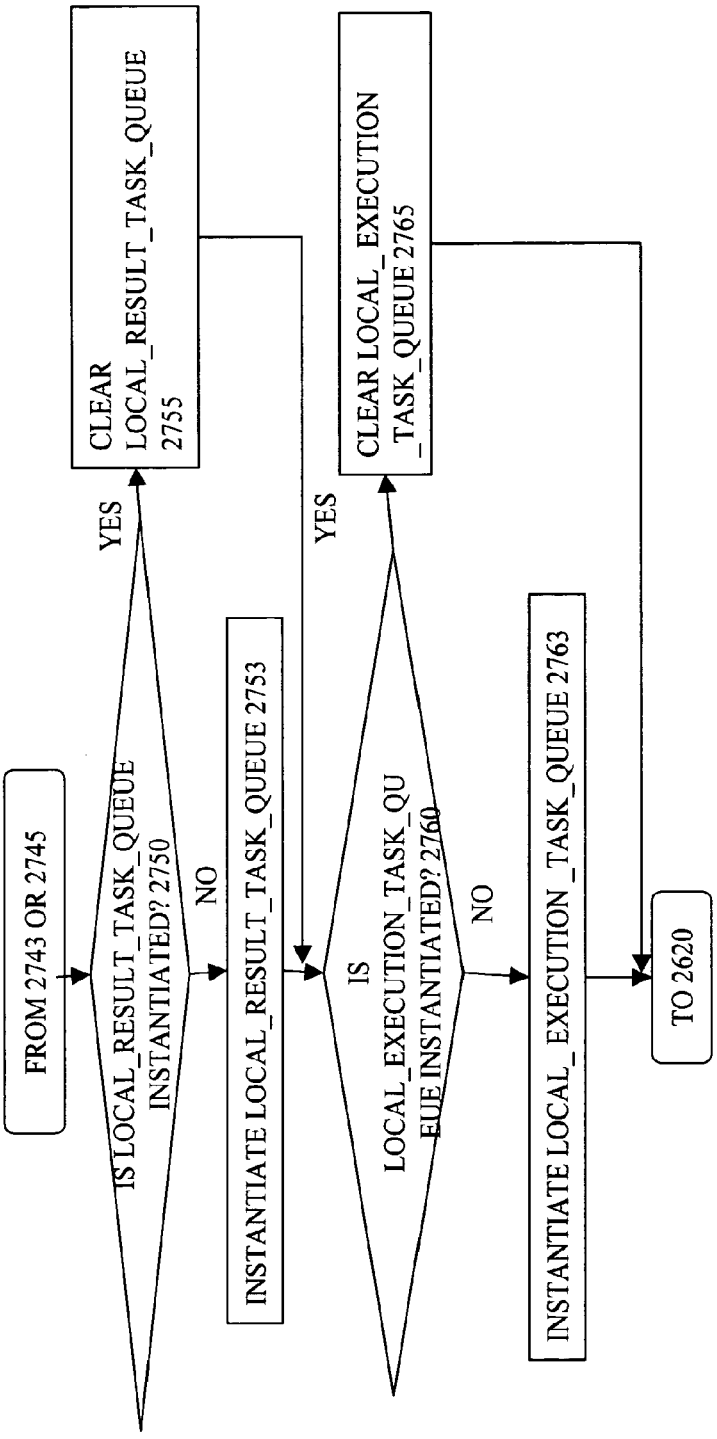

2610
FROM 2205
IS MT_RESULT_TASK_QUEUE INSTANTIATED? 2710
YES
CLEAR MT_RESULT_TASK_QUEUE 2715
NO
INSTANTIATE MT_RESULT_TASK_QUEUE 2713
IS MT_EXECUTION_TASK_QUEUE INSTANTIATED? 2720
YES
CLEAR MT_EXECUTION _TASK_QUEUE 2725
NO
INSTANTIATE MT_EXECUTION_TASK_QUEUE 2723
IS MP_RESULT_TASK_QUEUE INSTANTIATED? 2730
YES
CLEAR MP_RESULT_TASK_QUEUE 2735
NO
INSTANTIATE MP_RESULT_TASK_QUEUE 2733
IS MP_EXECUTION_TASK_QUEUE INSTANTIATED? 2740
YES
CLEAR MP_EXECUTION _TASK_QUEUE 2745
NO
INSTANTIATE MP_EXECUTION_TASK_QUEUE 2743
NO
TO 2750

FIGURE 27A

FIGURE 27B


FROM 2743 OR 2745
IS LOCAL_RESULT_TASK_QUEUE INSTANTIATED? 2750
YES
CLEAR LOCAL_RESULT_TASK_QUEUE 2755
NO
INSTANTIATE LOCAL_RESULT_TASK_QUEUE 2753
IS LOCAL_EXECUTION_TASK_QUEUE INSTANTIATED? 2760
YES
CLEAR LOCAL_EXECUTION _TASK_QUEUE 2765
NO
INSTANTIATE LOCAL_EXECUTION _TASK_QUEUE 2763
TO 2620

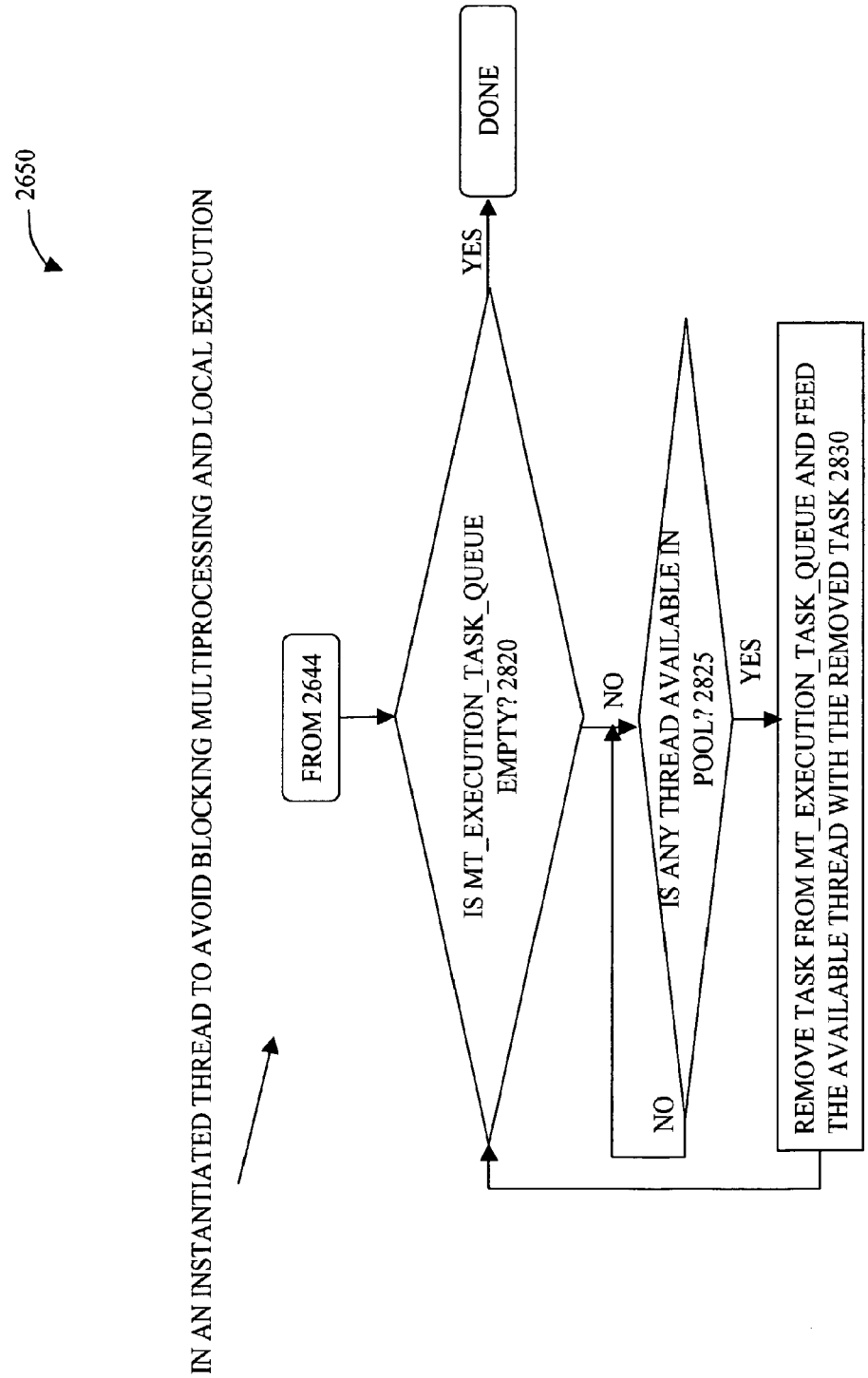

2650
IN AN INSTANTIATED THREAD TO AVOID BLOCKING MULTIPROCESSING AND LOCAL EXECUTION
FROM 2644
IS MT_EXECUTION_TASK_QUEUE EMPTY? 2820
YES
DONE
NO
IS ANY THREAD AVAILABLE IN POOL? 2825
NO
YES
REMOVE TASK FROM MT_EXECUTION_TASK_QUEUE AND FEED THE AVAILABLE THREAD WITH THE REMOVED TASK 2830

FIGURE 28A

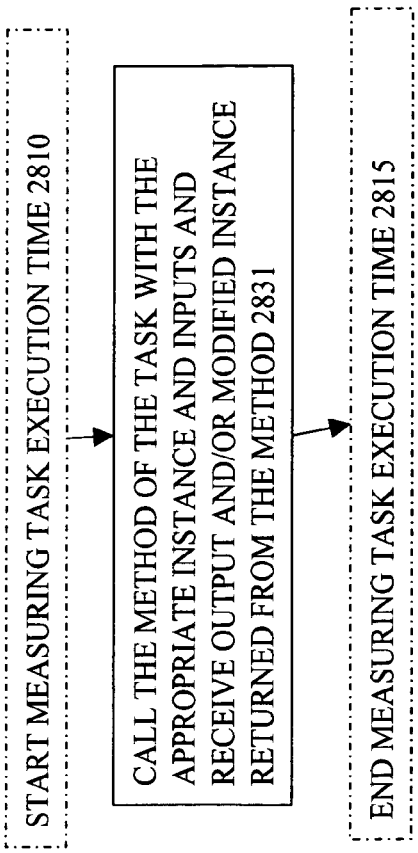


FIGURE 28B

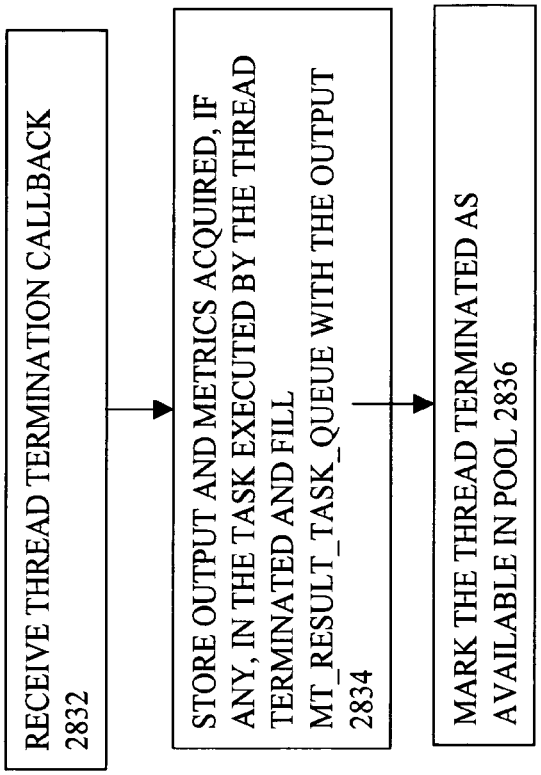


FIGURE 28C

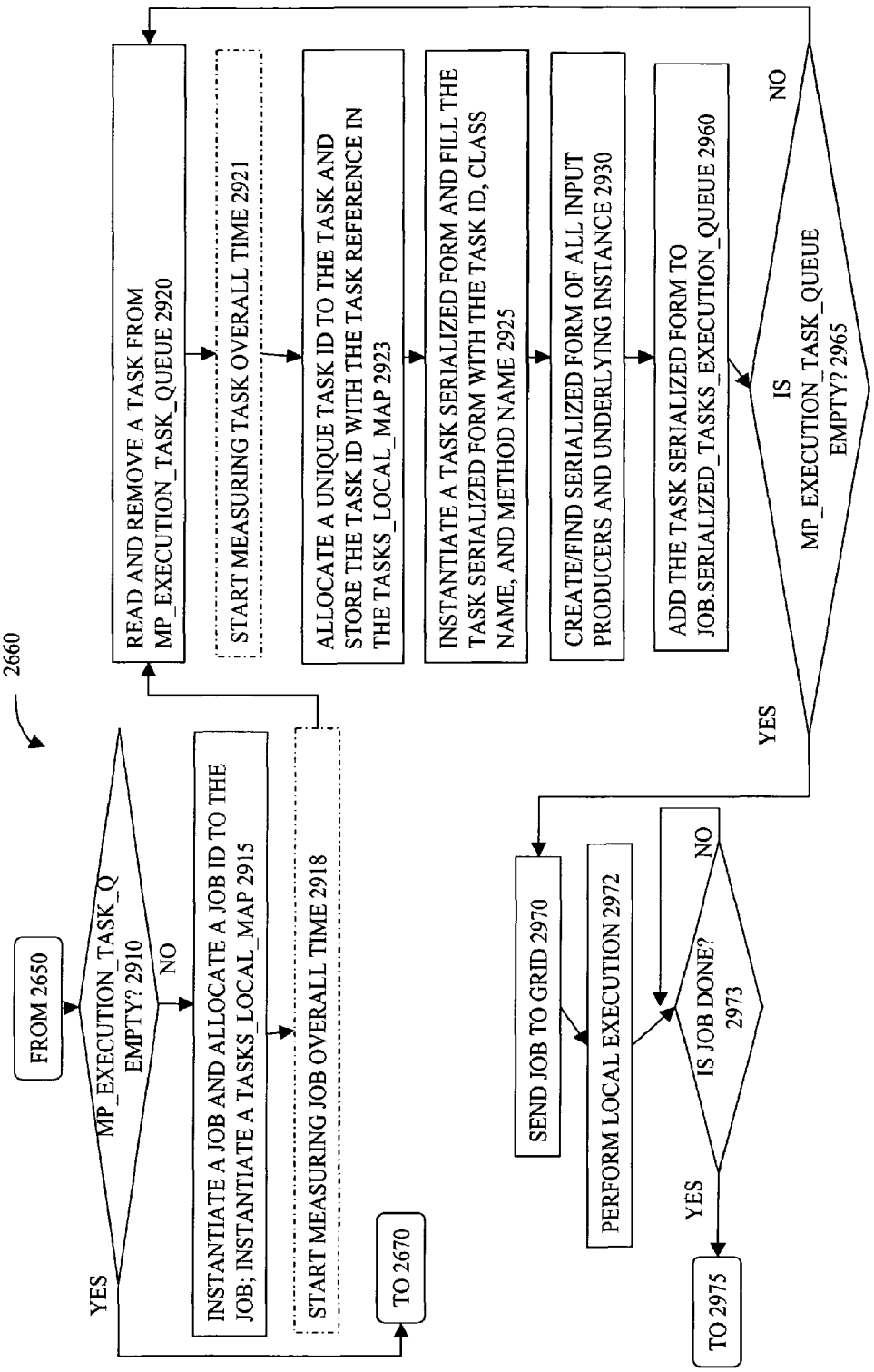

2660
FROM 2650
MP_EXECUTION_TASK_Q EMPTY? 2910
YES
NO
INSTANTIATE A JOB AND ALLOCATE A JOB ID TO THE JOB; INSTANTIATE A TASKS_LOCAL_MAP 2915
START MEASURING JOB OVERALL TIME 2918
TO 2670
READ AND REMOVE A TASK FROM MP_EXECUTION_TASK_QUEUE 2920
START MEASURING TASK OVERALL TIME 2921
ALLOCATE A UNIQUE TASK ID TO THE TASK AND STORE THE TASK ID WITH THE TASK REFERENCE IN THE TASKS_LOCAL_MAP 2923
INSTANTIATE A TASK SERIALIZED FORM AND FILL THE TASK SERIALIZED FORM WITH THE TASK ID, CLASS NAME, AND METHOD NAME 2925
CREATE/FIND SERIALIZED FORM OF ALL INPUT PRODUCERS AND UNDERLYING INSTANCE 2930
ADD THE TASK SERIALIZED FORM TO JOB.SERIALIZED_TASKS_EXECUTION_QUEUE 2960
IS MP_EXECUTION_TASK_QUEUE EMPTY? 2965
NO
YES
SEND JOB TO GRID 2970
PERFORM LOCAL EXECUTION 2972
IS JOB DONE? 2973
NO
YES
TO 2975
OPERATIONS PERFORMED FOR INSTRUMENTATION ONLY; MAY BE SKIPPED IF INSTRUMENTATION IS NOT ENABLED

FIGURE 29A

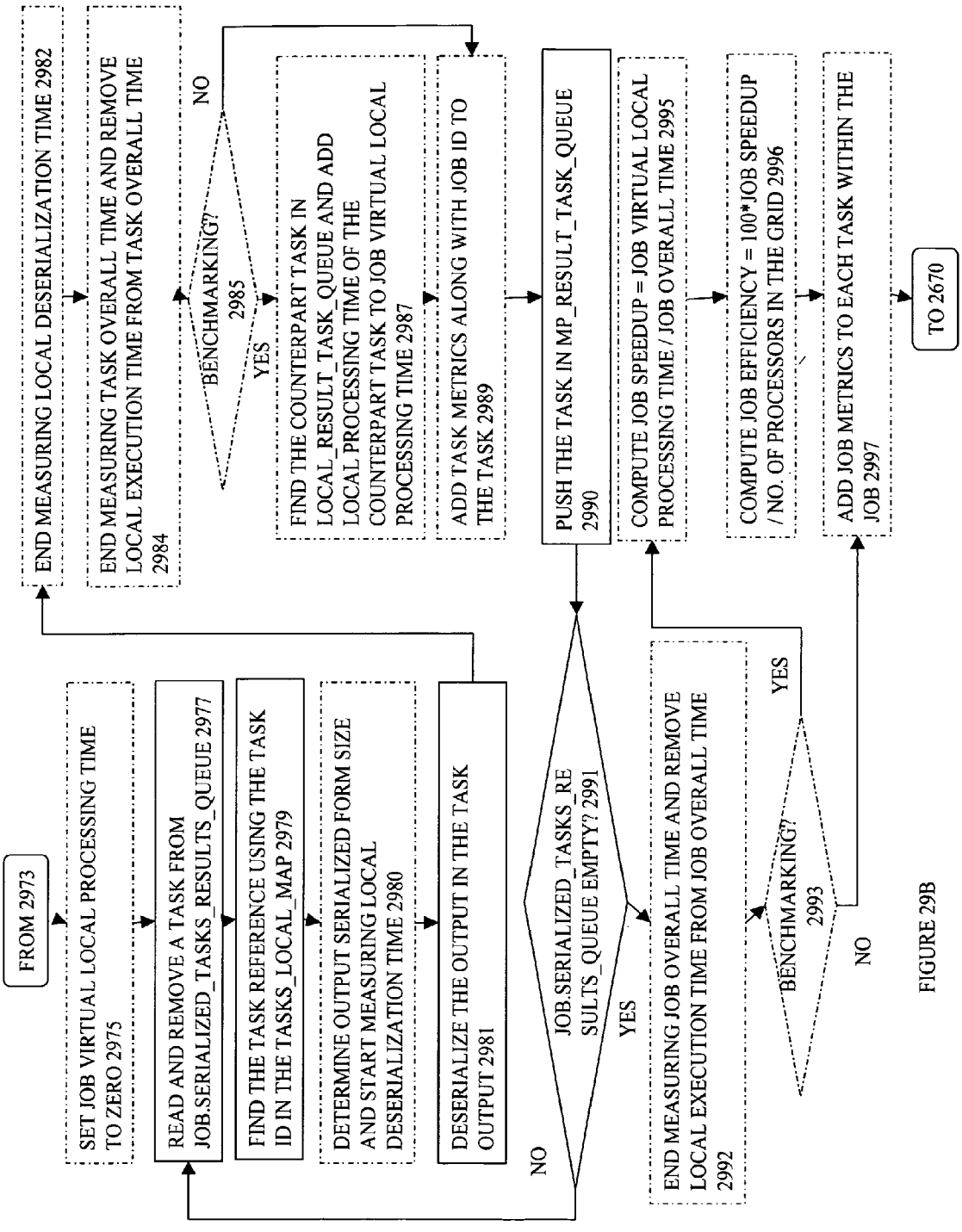

FROM 2973
SET JOB VIRTUAL LOCAL PROCESSING TIME TO ZERO 2975
READ AND REMOVE A TASK FROM JOB.SERIALIZED_TASKS_RESULTS_QUEUE 2977
FIND THE TASK REFERENCE USING THE TASK ID IN THE TASKS_LOCAL_MAP 2979
DETERMINE OUTPUT SERIALIZED FORM SIZE AND START MEASURING LOCAL DESERIALIZATION TIME 2980
DESERIALIZE THE OUTPUT IN THE TASK OUTPUT 2981
END MEASURING LOCAL DESERIALIZATION TIME 2982
END MEASURING TASK OVERALL TIME AND REMOVE LOCAL EXECUTION TIME FROM TASK OVERALL TIME 2984
BENCHMARKING? 2985
YES
NO
FIND THE COUNTERPART TASK IN LOCAL_RESULT_TASK_QUEUE AND ADD LOCAL PROCESSING TIME OF THE COUNTERPART TASK TO JOB VIRTUAL LOCAL PROCESSING TIME 2987
ADD TASK METRICS ALONG WITH JOB ID TO THE TASK 2989
PUSH THE TASK IN MP_RESULT_TASK_QUEUE 2990
JOB.SERIALIZED_TASKS_RESULTS_QUEUE EMPTY? 2991
NO
YES
END MEASURING JOB OVERALL TIME AND REMOVE LOCAL EXECUTION TIME FROM JOB OVERALL TIME 2992
COMPUTE JOB SPEEDUP = JOB VIRTUAL LOCAL PROCESSING TIME / JOB OVERALL TIME 2995
BENCHMARKING? 2993
YES
NO
COMPUTE JOB EFFICIENCY = 100*JOB SPEEDUP / NO. OF PROCESSORS IN THE GRID 2996
ADD JOB METRICS TO EACH TASK WITHIN THE JOB 2997
TO 2670

FIGURE 29B

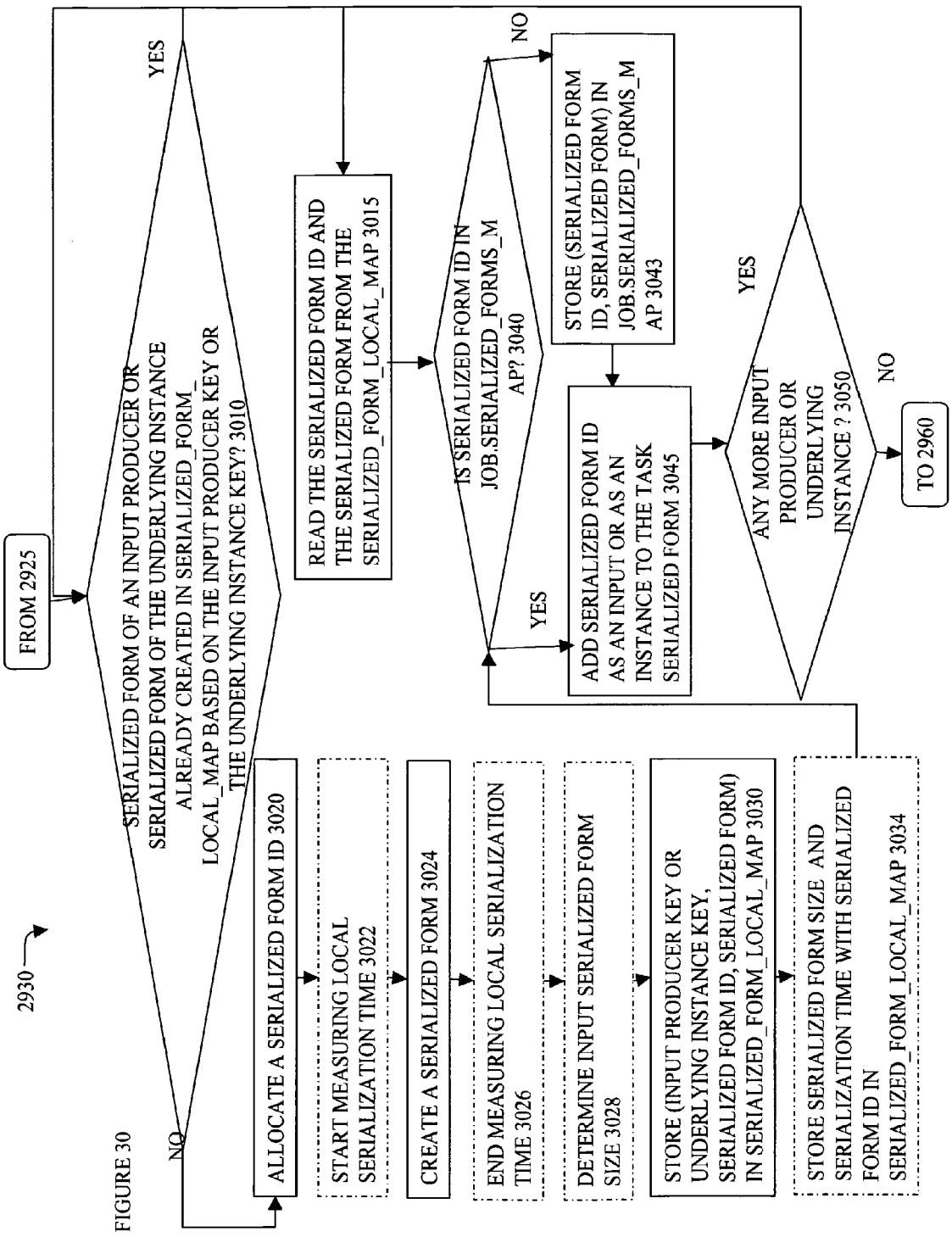

2930
FROM 2925
SERIALIZED FORM OF AN INPUT PRODUCER OR SERIALIZED FORM OF THE UNDERLYING INSTANCE ALREADY CREATED IN SERIALIZED_FORM_LOCAL_MAP BASED ON THE INPUT PRODUCER KEY OR THE UNDERLYING INSTANCE KEY? 3010
YES
NO
ALLOCATE A SERIALIZED FORM ID 3020
START MEASURING LOCAL SERIALIZATION TIME 3022
CREATE A SERIALIZED FORM 3024
END MEASURING LOCAL SERIALIZATION TIME 3026
DETERMINE INPUT SERIALIZED FORM SIZE 3028
STORE (INPUT PRODUCER KEY OR UNDERLYING INSTANCE KEY, SERIALIZED FORM ID, SERIALIZED FORM) IN SERIALIZED_FORM_LOCAL_MAP 3030
STORE SERIALIZED FORM SIZE AND SERIALIZATION TIME WITH SERIALIZED FORM ID IN SERIALIZED_FORM_LOCAL_MAP 3034
READ THE SERIALIZED FORM ID AND THE SERIALIZED FORM FROM THE SERIALIZED_FORM_LOCAL_MAP 3015
IS SERIALIZED FORM ID IN JOB.SERIALIZED_FORMS_MAP? 3040
YES
NO
ADD SERIALIZED FORM ID AS AN INPUT OR AS AN INSTANCE TO THE TASK SERIALIZED FORM 3045
STORE (SERIALIZED FORM ID, SERIALIZED FORM) IN JOB.SERIALIZED_FORMS_MAP 3043
ANY MORE INPUT PRODUCER OR UNDERLYING INSTANCE ? 3050
YES
NO
TO 2960

FIGURE 30

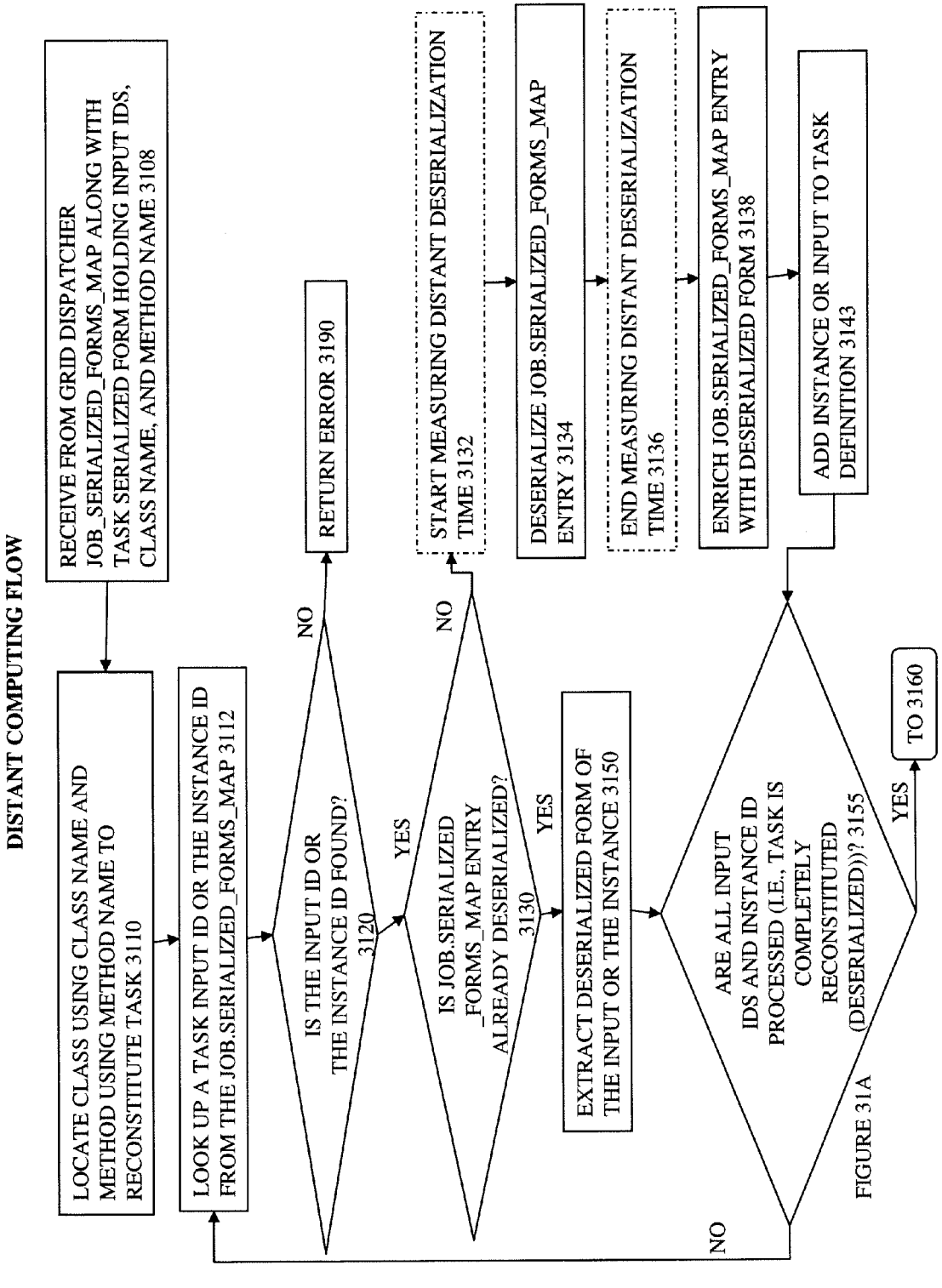

DISTANT COMPUTING FLOW
RECEIVE FROM GRID DISPATCHER JOB_SERIALIZED_FORMS_MAP ALONG WITH TASK SERIALIZED FORM HOLDING INPUT IDS, CLASS NAME, AND METHOD NAME 3108
LOCATE CLASS USING CLASS NAME AND METHOD USING METHOD NAME TO RECONSTITUTE TASK 3110
LOOK UP A TASK INPUT ID OR THE INSTANCE ID FROM THE JOB.SERIALIZED_FORMS_MAP 3112
IS THE INPUT ID OR THE INSTANCE ID FOUND? 3120
NO
RETURN ERROR 3190
YES
IS JOB.SERIALIZED _FORMS_MAP ENTRY ALREADY DESERIALIZED? 3130
NO
START MEASURING DISTANT DESERIALIZATION TIME 3132
YES
DESERIALIZE JOB.SERIALIZED_FORMS_MAP ENTRY 3134
EXTRACT DESERIALIZED FORM OF THE INPUT OR THE INSTANCE 3150
END MEASURING DISTANT DESERIALIZATION TIME 3136
ENRICH JOB.SERIALIZED_FORMS_MAP ENTRY WITH DESERIALIZED FORM 3138
ADD INSTANCE OR INPUT TO TASK DEFINITION 3143
ARE ALL INPUT IDS AND INSTANCE ID PROCESSED (I.E., TASK IS COMPLETELY RECONSTITUTED (DESERIALIZED))? 3155
NO
YES
TO 3160

FIGURE 31A

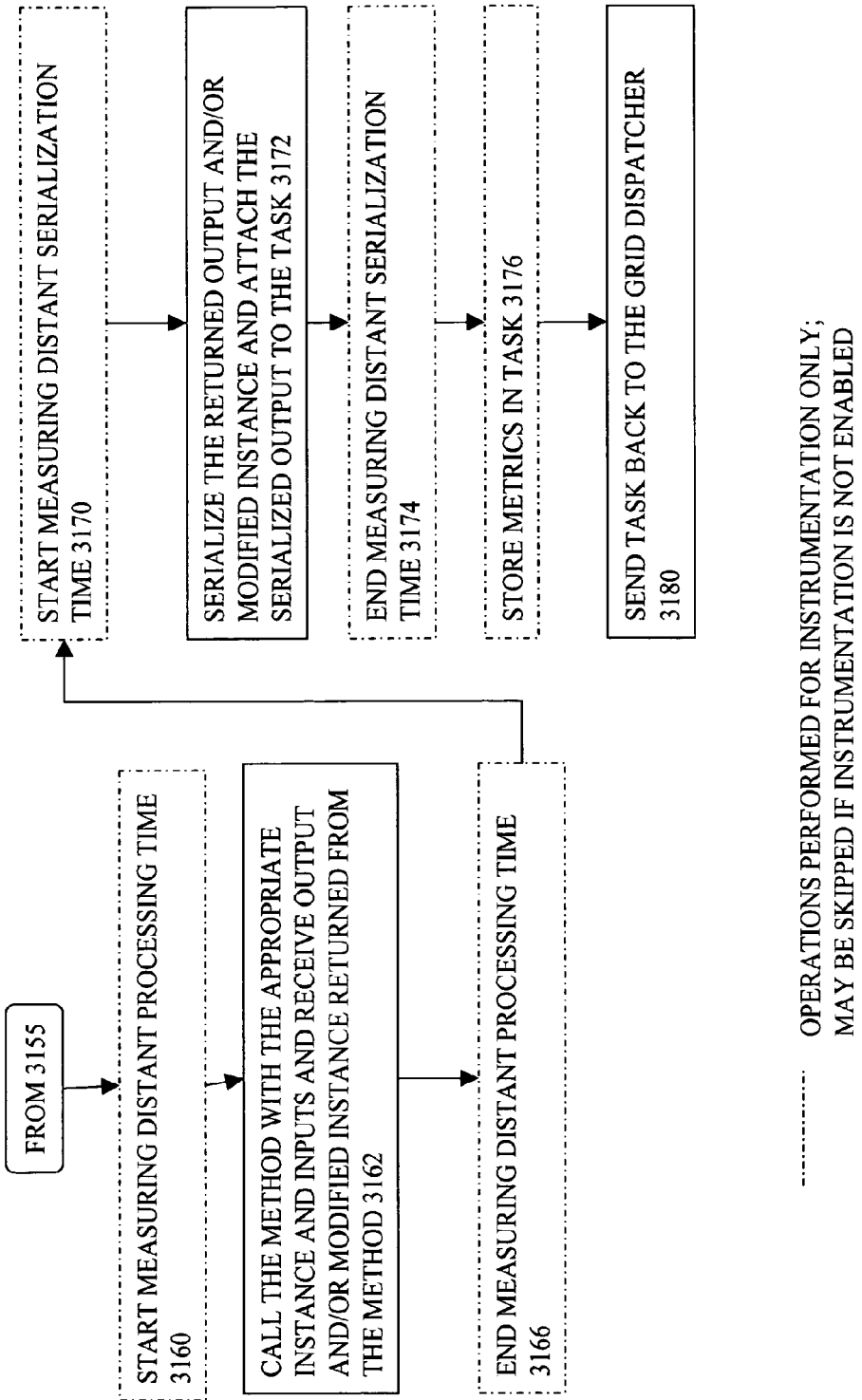

FROM 3155
START MEASURING DISTANT PROCESSING TIME 3160
CALL THE METHOD WITH THE APPROPRIATE INSTANCE AND INPUTS AND RECEIVE OUTPUT AND/OR MODIFIED INSTANCE RETURNED FROM THE METHOD 3162
END MEASURING DISTANT PROCESSING TIME 3166
START MEASURING DISTANT SERIALIZATION TIME 3170
SERIALIZE THE RETURNED OUTPUT AND/OR MODIFIED INSTANCE AND ATTACH THE SERIALIZED OUTPUT TO THE TASK 3172
END MEASURING DISTANT SERIALIZATION TIME 3174
STORE METRICS IN TASK 3176
SEND TASK BACK TO THE GRID DISPATCHER 3180
OPERATIONS PERFORMED FOR INSTRUMENTATION ONLY; MAY BE SKIPPED IF INSTRUMENTATION IS NOT ENABLED

FIGURE 31B

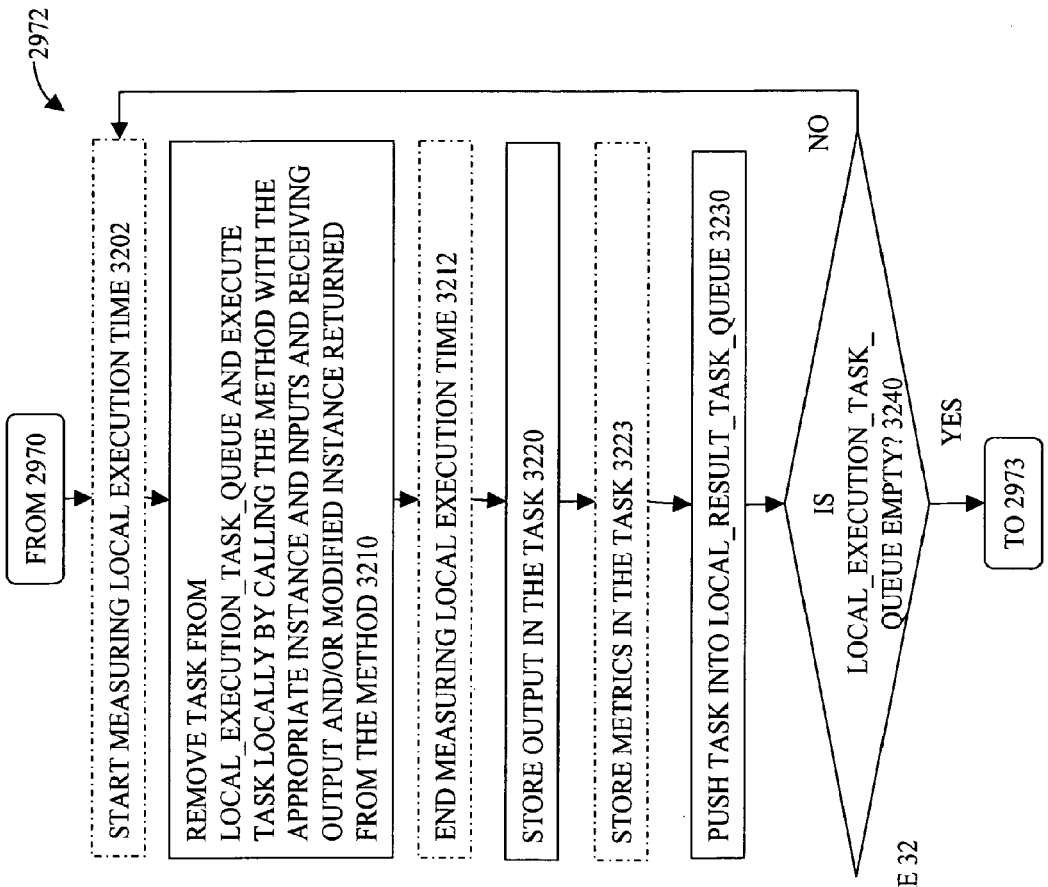

2972
FROM 2970
START MEASURING LOCAL EXECUTION TIME 3202
REMOVE TASK FROM LOCAL_EXECUTION_TASK_QUEUE AND EXECUTE TASK LOCALLY BY CALLING THE METHOD WITH THE APPROPRIATE INSTANCE AND INPUTS AND RECEIVING OUTPUT AND/OR MODIFIED INSTANCE RETURNED FROM THE METHOD 3210
END MEASURING LOCAL EXECUTION TIME 3212
STORE OUTPUT IN THE TASK 3220
STORE METRICS IN THE TASK 3223
PUSH TASK INTO LOCAL_RESULT_TASK_QUEUE 3230
IS LOCAL_EXECUTION_TASK_QUEUE EMPTY? 3240
NO
YES
TO 2973

FIGURE 32

PARALLELIZATION AND INSTRUMENTATION IN A PRODUCER GRAPH ORIENTED PROGRAMMING FRAMEWORK

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation of application Ser. No. 11/607,196, filed Dec. 1, 2006, which is hereby incorporated by reference.

BACKGROUND

1. Field

Embodiments of the invention relate to the field of computers; and more specifically, to the field of programming and executing code with a runtime.

2. Background

Object-Oriented Programming

Object-oriented programming is a computer programming paradigm. The idea behind object-oriented programming is that a computer program may be seen as comprising a collection of individual units (called objects or instances) that act on each other, as opposed to a traditional view in which a program may be seen as a collection of functions, or simply as a list of instructions to the computer. An object is a language mechanism for binding data with methods that operate on that data. Each object is capable of being called through methods, processing data, and providing results to other objects. Each object can be viewed as an independent machine or actor with a distinct role or responsibility.

A reflective object-oriented language is a programming language that has a particular set of characteristics (e.g., classes, objects/instances, inheritance, reflection, etc.), whereas a reflective object-based language is sometimes used to label a programming language that has some subset of those characteristics (e.g., objects). For purposes of this document, the phrases "object-oriented source code" and "object-oriented code" will be used to refer to code written in a language that has such characteristics (e.g., code written in a reflective object-oriented language, code written in a reflective object-based language). While procedural languages, non-reflective object-oriented languages, and non-reflective object-based languages are programming languages that do not typically support such characteristics, transformation techniques may be used to provide such characteristics (e.g., through emulation) to code properly written in such languages; and thus, such techniques transform such languages into a reflective object-based language or reflective object-oriented language. (These techniques need not emulate all characteristics of object oriented or based languages, but may emulate only those characteristics which are of interest to the rest of this document) For purposes of this document, the phrases "object-oriented source code" and "object-oriented code" will also be used to refer to such transformed procedural, non-reflective object-oriented, and non-reflective object-based language code. By way of example, and not limitation, this document primarily describes object-oriented source code written in a reflective object-oriented language. Also, the terms object and instance are used interchangeably herein.

Used mainly in object-oriented programming, the term method refers to a piece of code that is exclusively associated either with a class (called class methods, static methods, or factory methods) or with an object (called instance methods). Like a procedure in procedural programming languages, a method usually consists of a sequence of statements to perform an action, a set of input parameters to parameterize those actions, and possibly an output value of some kind that is returned.

When programmers write a program using an object-oriented language, the resulting code can be conceptually viewed as including four basic types of code. The first type includes commands that operate on input instance(s) to provide output instance(s) (referred to herein as "transformation" code); typically written as methods (referred to herein as "transformation" methods). The second type includes instance instantiation commands that cause the runtime to instantiate instances of classes (referred to herein as "instance instantiation" code). The third type includes property manipulation commands (referred to herein as "data preparation" code) to invoke property methods (accessors, mutators, etc.) of the above instances. The fourth type includes sequences of commands that cause method invocation sequencing using the appropriate instances (where the appropriate instances include the instances to use as arguments, the instances to be used by instance methods, and the meta class instances used by class methods) to specify what transformation methods of what instances to invoke, in which order, and with which parameters of which instances responsive to the changes made by data preparation code (referred to herein as "manual invocation sequencing" code). The manual invocation sequencing code is sometimes written as methods separate from the transformation methods, and thus the manual invocation sequencing code includes sequences of invocation commands for the transformation methods. A program typically iterates between data preparation code and manual invocation sequencing code (which may also dip into the instance instantiation code), which in turn invokes transformation code (which may also dip into the instance instantiation code and data preparation code types). It should be noted that this is a conceptual representation of a program, and thus, should not be taken as an absolute with regard to how to view a program.

Runtime

The term runtime is used herein to refer to a program or library of basic code that runs other code written in the same and/or a different language. Thus, a runtime is a collection of utility functions that support a program while it is running, including working with the operating system to provide facilities such as mathematical functions, input and output. These make it unnecessary for programmers to continually rewrite basic capabilities specified in a programming language or provided by an operating system. Since the demarcation between a runtime and an operating system can be blurred, the term runtime is used herein to refer to code separate from the operating system and/or code that is part of the operating system.

Early runtimes, such as that of FORTRAN, provide such features as mathematical operations. Other languages add more sophisticated features—e.g., memory garbage collection, often in association with support for objects. More recent languages tend to have considerably larger runtimes with considerably more functionality. Many object-oriented languages also include a system known as the "dispatcher" and "class loader." The Java Virtual Machine (JVM) is an example of such a runtime: it also interprets or compiles the portable binary Java programs (byte-code) at run time. The common language runtime (CLR) framework is another example of a runtime.

Programming and Execution Framework

One framework within which applications are provided to end users includes three basic divisions. The first division

includes the creation of the operating system and runtime. This first division is performed by programmers with highly advanced programming skills. When working in this division, programmers are respectively referred to as operating system programmers and runtime programmers. When creating a runtime for an object-oriented language, the runtime programmers include support for executing the various types of commands used in transformation code, instance instantiation code, data preparation code, and manual invocation sequencing code (e.g., instance instantiation commands, data preparation commands, and method invocation commands).

The second division includes the creation of object-oriented application source code to be run by the runtime. The second division is again performed by programmers with highly advanced programming skills, as well as an understanding of the business objectives of the application. When working in this division, programmers are referred to as application programmers. When creating an application in an object-oriented programming language, the application programmers write the specific transformation code, instance instantiation code, data preparation code, and manual invocation sequencing code for the specific application being created. As part of this, if the application requires a graphical user interface, the application programmers also design and code the graphical user interface for the specific application; and thus are also referred to as application designers.

The third division includes the use of application programs being run by the runtime. The third division is performed by end users that need not have any programming skills.

Manual Invocation Sequencing Code

The greatest costs typically associated with the creation of an application involve the debugging and/or optimization of the manual invocation sequencing code. For each opportunity for data to change, the application programmer must consider its effect and write manual invocation sequencing code to cause the appropriate transformation methods of the appropriate instances to be invoked in the appropriate order with the appropriate inputs. Exemplary mistakes made by application programmers include: 1) invoking the appropriate transformation methods of the appropriate instances in the wrong order; 2) forgetting to include commands to cause the one or more required transformation methods of instances to be invoked responsive to some data being changed; 3) including commands to cause unnecessary transformation methods of instances to be invoked responsive to some data being changed (e.g., including commands to invoke transformation methods of instances that are not affected by the change in data), etc.

By way of example, one technique of generating manual invocation sequencing code is the use of the observer pattern (sometimes known as "publish subscribe") to observe the state of an instance in a program. In the observer pattern, one or more instances (called observers or listeners) are registered (or register themselves) to observe an event which may be raised by the observed object (the subject). The observed instance, which may raise an event, generally maintains a collection of the registered observers. When the event is raised, each observer receives a callback from the observed instance (the observed instance invokes a "notify" method in the registered observers). The notify function may pass some parameters (generally information about the event that is occurring) which can be used by the observers. Each observer implements the notify function, and as a consequence defines its own behavior when the notification occurs.

The observed instance typically has a register method for adding a new observer and an unregister method for removing an observer from the list of instances to be notified when the event is raised. Further, the observed instance may also have methods for temporarily disabling and then reenabling calls to prevent inefficient cascading of a number of related updates. Specifically, callbacks called in response to a property value change often also change values of some other properties, triggering additional callbacks, and so on.

When using the observer pattern technique, application programmers writing manual invocation sequencing code specify what methods of what instances to call, in which order, and with which inputs by registering, unregistering, disabling, and reenabling observers to different observed instances, as well as writing the notify and callback methods for each. More specifically, the relationship between observer and observed instances is locally managed (by the observed instance alone, without synchronization with other observed instances) within the observer pattern, and thus the manual invocation sequencing code needed to synchronize events from multiple observed instances is typically part of the specific callback methods of each observer.

Overwriting, Volatile Call Stack

Typical runtimes use an overwriting, volatile call stack to track currently invoked, uncompleted calls. An overwriting, volatile call stack is overwriting in that it pops off and discards entries as each call is completed, and volatile in that it is discarded and rebuilt on every execution. Typical runtimes use overwriting, volatile call stacks because typical runtimes combine the building of the overwriting, volatile call stack with the actual invocation of the appropriate transformation methods of the appropriate instances with the appropriate inputs responsive to execution of the manual invocation sequencing code. In sum, responsive to execution of manual invocation sequencing code, a typical runtime determines the transformation method of instance sequencing call by call (as each call is made) and maintains the overwriting, volatile call stack to track only currently invoked, uncompleted calls.

Program Execution and Parallelization

Conventionally, methods in a program are executed sequentially based on the manual invocation sequencing code. To improve the efficiency and speed of execution, some methods may be executed in parallel in systems that support parallelization. In general, parallelization in computing is the execution of multiple processes, tasks, or threads, simultaneously. To implement parallelization, application programmers may identify methods that are desired to be executed in parallel, and then rewrite the manual invocation sequencing code to cause the methods identified to be executed in parallel.

Currently, common parallelization mechanisms supported in computing include multiprocessing and multithreading. In multiprocessing, an application program is typically divided into multiple tasks. Each task is a logically high level, discrete, independent section of computational work executable by a processor. To achieve parallization, at least some of the tasks are executed on multiple processors simultaneously. The processors may be coupled to each other via a network and be collectively referred to as a grid. The processors in the grid may include local processors, distant processors, or a combination of both.

Besides multiprocessing, another common parallelization mechanism is multithreading. A thread is a local process to execute a task. A processor that supports multithreading may execute multiple threads substantially in simultaneously. One example of such a processor is a multi-core processor, where each core of the multi-core processor may execute a thread.

By way of example, one conventional technique in parallelization is to analyze the source code of an application program to extract a configuration of the application program.

Based on the configuration, the application program is divided into a number of sub-programs, which are presented in a graph based on the sub-programs' parent-child relationships. These sub-programs are executed in parallel based on the sub-programs' parent-child relationships.

In some conventional computing system, analysis of the intermediate code generated from the source code may be performed to achieve parallelization. For example, analysis of intermediate code (e.g., assembly language) and parallelization is done during compilation. A parallelizer of the compiler converts the intermediate code into a parallelly executable form. An execution order determiner determines the order of the basic blocks to be executed. An expanded basic building block parallelizer subdivides the basic building blocks into execution units, each made up of parallelly executable instructions. Analysis of dependency is done on an instruction basis.

However, the conventional techniques described above all require analysis of the manual invocation sequencing code in the application program, which is written by application programmers. Thus, the burden of parallelization is put onto the application programmers because great care has to be taken when writing the manual invocation sequencing code in order for the parallelization to be performed correctly. Thus, the application programmers need to possess a relatively high level of programming skill.

To make the job of application programmers easier, some conventional techniques have been developed to perform parallelization of application programs without requiring high level of programming skill. For example, special language constructs and special wrapper classes around regular data types are provided to execute a sequential program in parallel. Programmers are not required to write a "parallel program" in order to have parallel execution of parts of the program. A parallel procedure is specified at calling point by specifying a parallel procedure identifier and its arguments to the system. Execute parallel function to execute different parts in parallel is provided. Parallel procedures may be written by making a new class derived from a common class corresponding to each parallel procedure in the program. The system resolves dependencies at run time and parallelization is done to the level where actual dependency is encountered. The compiler may determine whether arguments can be modified in the parallel procedure through analysis of the control flow graph of the parallel procedure.

In another conventional computing system, a database manager is used in executing user-defined functions in an application program without the need of hard-coding all the parallelism support in the computer program itself. A database table is defined with instructions the user wants to execute in parallel. A user-defined function is then defined that executes the instructions in the table. The database manager provides parallelism by executing multiple tasks in parallel in the user-defined function.

Software Instrumentation

In general, software instrumentation refers to techniques for observing the behavior of one or more application programs and collecting metrics relevant to the application programs and the execution thereof. Thus, software instrumentation is a valuable tool in development as well as maintenance of an application program as the application program and/or the execution of the application program may be improved in various ways based on the behavior of the application program and the metrics collected.

Currently, various techniques have been developed to implement software instrumentation. For example, one technique is to add software modules or code to record the execution history of an application program such that future execution of the application program may be managed based on the execution history recorded. In another example, a compiler generates instruction and metadata for monitoring and collecting metrics. If a selected indicator is associated with an instruction, counting of events associated with the execution of the instruction is enabled. Then the number of times an instruction is executed is counted. After execution of the application program, hotspots are identified to determine performance improvement methodology and source code of the application program may be modified accordingly to implement performance improvement methodology.

Another conventional technique in instrumentation is to use the intermediate representation (IR) data generated from the source code of an application program. Specifically, a compiler generates IR data from source code. A code instrumentation module acts on the IR data to construct an IR tree and to add instrumentation to the IR data based on the IR tree. Then the compiler finishes compilation by converting the IR data with instrumentation into object code. A class instance can be instrumented using an instrumentation library (hereinafter, an instrumentation DLL). A virtual machine (VM) runtime module may run the instrumented class instance. There are declarations of method names and parameters in the byte code in the class instance. A special designator indicates that the executable portions correspond to the declared methods are found in some blocks of native code separate from the VM runtime module. For example, the instrumented Java VM byte code may be monitored during execution by a monitor process and a monitor library (a.k.a. a monitor DLL).

Object-Relational Mapping

Object-Relational mapping is a programming technique that links relational databases to object-oriented language concepts, creating (in effect) a "virtual object database." Some object-relational mappers automatically keep the loaded instances in memory in constant synchronization with the database. Specifically, after construction of an object-to-SQL mapping query, first returned data is copied into the fields of the instances in question, like any object-SQL mapping package. Once there, the instance has to watch to see if these values change, and then carefully reverse the process to write the data back out to the database.

Hibernate 3.0 is an object-relational mapping solution for Java and CLR (Jboss® Inc. of Atlanta, Ga.). Thus, Hibernate provides a framework for mapping an object-oriented domain model to a traditional relational database. Its goal is to relieve the developer from some common data persistence-related programming tasks. Hibernate takes care of the mapping from classes to database tables (and from object-oriented data types to SQL data types), as well as providing data query and retrieval facilities. Hibernate is instance centric and builds graphs representing relationships between instances.

Inversion of Control and the Dependency Inversion Principle

Inversion of Control, also known as IOC, is an object-oriented programming principle that can be used to reduce coupling (the degree to which each program module relies on each other module) inherent in computer programs. IOC is also known as the Dependency Inversion Principle. In IOC, a class X depends on class Y if any of the following applies: 1) X has a Y and calls it; 2) X is a Y; or 3) X depends on some class Z that depends on Y (transitivity). It is worth noting that X depends on Y does not imply Y depends on X; if both happen to be true, it is called a cyclic dependency: X can't then be used without Y, and vice versa.

In practice, if an object x (of class X) calls methods of an object y (of class Y), then class X depends on Y. The depen-

dency is inverted by introducing a third class, namely an interface class I that must contain all methods that X might call on Y. Furthermore, Y must be changed such that it implements interface I. X and Y are now both dependent on interface I and class X no longer depends on class Y (presuming that X does not instantiate Y). This elimination of the dependency of class X on Y by introducing an interface I is said to be an inversion of control (or a dependency inversion). It must be noted that Y might depend on other classes. Before the transformation had been applied, X depended on Y and thus X depended indirectly on all classes that Y depends on. By applying inversion of control, all those indirect dependencies have been broken up as well. The newly introduced interface I depends on nothing.

The Spring Framework is an open source application framework for the Java platform that uses IOC and dependency inversion. Specifically, central in the Spring Framework is its Inversion of Control container that provides a means of configuring and managing Java objects. This container is also known as BeanFactory, ApplicationContext or Core container. Examples of the operations of this container are: creating objects, configuring objects, calling initialization methods and passing objects to registered callback objects. Objects that are created by the container are also called Managed Objects or Beans. Typically the container is configured by loading XML files that contain Bean definitions. These provide all information that is required to create objects. Once objects are created and configured without raising error conditions they become available for usage. Objects can be obtained by means of Dependency lookup or Dependency injection. Dependency lookup is a pattern where a caller asks the container object for an object with a specific name or of a specific type. Dependency injection is a pattern where the container passes objects by name to other objects, either via constructors, properties or factory methods. Thus, the Spring Framework is memory centric and builds graphs representing relationships between instances.

Graphing Tools

Javadoc™ is a tool that parses the declarations and documentation comments in a set of Java source files and produces a corresponding set of HTML pages describing (by default) the public and protected classes, nested classes (but not anonymous inner classes), interfaces, constructors, methods, and fields (Sun Microsystems®, Inc. of Santa Clara, Calif.). Javadoc can be used to generate the API (Application Programming Interface) documentation or the implementation documentation for a set of source files. Javadoc is class and method centric and builds graphs representing the relationships between the combination of classes and their methods.

Another system for designing software applications includes graphs of objects analyzed by an interpreter to represent and reproduce a computer application. This system utilizes prewritten programming classes stored in code libraries, which can be written to follow the design patterns described in "Design Patterns" by Gamma et al, Addison Wesley 1995, "Patterns in Java" by Grand, Wiley Computer Publishing 1998, and/or high level Computer Aided Software Engineering (CASE) tools. More specifically, some such classes are based on the Observer behavioral pattern. The prewritten code libraries represent application state nodes, processing logic, and data flow of the system between various application states (i.e., the pre-written data elements of the application), so that a user need not write, edit, or compile code when creating a software application. Instead, a user manually edits a software application in a Graphical User Interface by editing visual objects associated with a current application state node, such as data within the application state node or processes performed within the application state node. Then, based on the changes made by the user to the current application state node, the interpreter displays the updated application state to the user for the application state which has just been edited. The system may then transition along a user-defined transitional edge to another application state where the user may optionally edit the next application state or the transitional edge. Changes to a graph may be made to instances of the graph which are implemented by the interpreter while the software application is running

This system for designing software applications may include visual representations of a running software application that can be made "usable" with an application controller. When a user changes visual objects, representing the running software application, the controller uses the input to induce the interpreter to make the change to the graph. The controller then waits for more changes. Further, visual representations of such software applications may be imported or exported as XML documents that describe the visual representation of the application, and thereby the software application.

In order to edit and/or create a software application, in the form of a visual representation of nodes, directed edges, and application states, an application program interface and an application editor may further be included in the system. Key words, and associated definitions, from the pre-written code libraries, enable application developers to manually define a software application, processing steps, as well as the visual representation of a software application by providing graphical representations, within an editor, of a graph application which closely correlates to the actual application structure. A user defines a new application through an "application definition wizard," which after certain preliminary matters are fulfilled, displays the new application as a graph component within the editor workspace. A user further interacts with an application by making selections from displayed lists of precreated possible application components and dragging and dropping components onto the workspace using a PC's mouse and keyboard. A user may select components and "drag" them over existing components. When a new component is "dropped" on an existing component, the new component becomes a child of the existing component within an application graph. The relationships of components within the application are manually defined by the user's selections within the editor. Thus a tree structure representing an application is built by the user. As the application is created, a user can select an application navigator viewer to display a tree view of the constructed application making it possible to select and edit any component of the application. The editor interface processes user inputs and selections including creating or deleting application elements, updating component attributes, and updating display properties of an application.

The system described above, while utilizing visual representations of software applications, may also be used as a visual programming tool for defining and updating relational databases. The system utilizes XML descriptions of visual representation of software applications. A tool parses and interprets the XML descriptions to produces equivalent relational database table schemas, as well as changes thereto. When data is changed within a visual representation of a software application, a description of the change is stored along with other changes in a journal file and then processed as a group. An intermediate program (a java application operating on its own thread) performs transactions between the visual representation of the software application and the relational database. The java application polls (i.e., checks) the journal of changes to nodes of the visual representation (i.e., data in database), and if there are changes, makes the changes to the database. Thus, by altering data within the visual rep-

resentation, the system updates a database. A similar application stands between the visual representation of the software application and the database to handles requests for data from the database.

Another system for analyzing software is called a Code Tree Analyzer (CTA). A CTA analyzes static source code written in an object-oriented programming language. The CTA generates a symbol table and a call tree from the static source code. Using the symbol table, the CTA generates a class diagram. Likewise, using the call tree, the CTA generates a sequence diagram. The class diagram illustrates the relationship between a user selected class and classes related to the user selected class. The sequence diagram illustrates the sequence in which different methods are called. Using both the class diagram and the sequence diagram, the CTA generates a design artifact representative of the static source code. When the user modifies the design artifact, the CTA identifies impacted portions of the source code using the sequence diagram. The design artifact is used for code maintenance and/or reverse engineering of the static source code.

U.S. Pat. No. 5,966,072 describes use of a graph to invoke computations directly. Getting information into and out of individual processes represented on the graph, moving information between the processes, and defining a running order for the processes, are discussed. The described arrangement adds "adaptor processes", if necessary, to assist in getting information into and out of processes.

BRIEF SUMMARY

Embodiments of parallelization and/or instrumentation in a producer graph oriented programming framework have been presented. In one embodiment, a request to run an application program is received, wherein object-oriented source code of the application program includes methods and producer dependency declarations, wherein the producer dependency declaration for a given method identifies a set of zero or more producers with outputs that are an input to the given method, wherein a producer is at least an instance and a method associated with that instance. Further, execution of the application program may be parallelized based on dependency between producers of the application program using the runtime. In some embodiments, the application program is instrumented using the runtime.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention may best be understood by referring to the following description and accompanying drawings that are used to illustrate embodiments of the invention. In the drawings:

FIG. **1**A is a block diagram illustrating the relationship of a producer dependency declaration for a method of a class in object oriented-source code to an instance of a producer based on that method from a given instance, according to one embodiment of the invention;

FIG. **1**B illustrates exemplary relationships between the producer **110**A and the parent producer **114**A.**1** according to one embodiment of the invention;

FIG. **1**C illustrates exemplary relationships between the producer **110**A and the child producer **112**A.**1** according to one embodiment of the invention;

FIG. **1**D illustrates some additional exemplary combinations of relationships of parent producers **114** and child producers **112** to producer **110**A according to one embodiment of the invention;

FIG. **1**E illustrates that different instances of the same class can have producers based on the same and/or different methods according to one embodiment of the invention;

FIG. **2** is a block diagram illustrating the reusability of a runtime with producer graph oriented programming support according to one embodiment of the invention;

FIG. **3**A is a block diagram illustrating a runtime with producer graph oriented programming support according to one embodiment of the invention;

FIG. **3**B is a block diagram illustrating a runtime with producer graph oriented programming support that also supports incremental execution and overridden producer outputs according to one embodiment of the invention;

FIG. **4**A is a block diagram illustrating the discovery and building of an exemplary producer graph according to one embodiment of the invention;

FIG. **4**B is a block diagram illustrating the initial execution of the producer graph of FIG. **4**A according to one embodiment of the invention;

FIG. **4**C is a block diagram illustrating the incremental execution of the producer graph of FIG. **4**B according to one embodiment of the invention;

FIG. **4**D is a block diagram illustrating the incremental execution of the producer graph of FIG. **4**B after dependent producer **2** has been overridden according to one embodiment of the invention;

FIG. **4**E is a block diagram illustrating the incremental execution of the producer graph of FIG. **4**B after dependent producer **2** has been overridden and independent source producer **3** has been modified according to one embodiment of the invention;

FIG. **5**A is a block diagram illustrating the discovery and building of an exemplary producer graph including an unresolved dependency according to one embodiment of the invention;

FIG. **5**B is a block diagram illustrating the initial execution of the producer graph of FIG. **5**A and the resolution of the unresolved dependency according to one embodiment of the invention;

FIG. **5**C is a block diagram illustrating the initial execution of the producer graph of FIG. **5**A and/or the reexecution of the producer graph of FIG. **5**B according to one embodiment of the invention;

FIG. **5**D is a block diagram illustrating the initial execution of the producer graph of FIG. **5**A and/or the reexecution of the producer graph of FIG. **5**B or **5**C according to one embodiment of the invention;

FIG. **6** is a flow diagram a logical execution flow of a runtime client and its relationship to a runtime with producer graph oriented programming support according to one embodiment of the invention;

FIG. **7**A illustrates pseudo code of a producer dependency declaration for a method using shortcut dependencies according to one embodiment of the invention;

FIG. **7**B is a block diagram of exemplary producers according to one embodiment of the invention;

FIG. **7**C illustrates pseudo code of a producer dependency declaration for a method using a non-shortcut dependency, and illustrates a block diagram of exemplary producers according to one embodiment of the invention;

FIG. **7**D illustrates pseudo code of a producer dependency declaration for a method using a non-shortcut dependency according to one embodiment of the invention;

FIG. **7**E is a block diagram of exemplary producers according to one embodiment of the invention;

FIG. 7F is a block diagram of an exemplary dependencies through use of a UpwardDependency with a dependency determination producer according to one embodiment of the invention;

FIG. 7G is a block diagram of possible exemplary dependencies through use of a WeaklyConstrainedDependency with a dependency determination producer according to one embodiment of the invention;

FIG. 7H illustrates exemplary producer graphs of standard producers according to one embodiment of the invention;

FIG. 7I illustrates one example of producer dependencies and dependency determination producers for discovering, resolving, and building the producer graph of FIG. 7H;

FIG. 8A is a block diagram illustrating a first exemplary framework within which applications are provided to end users according to one embodiment of the invention;

FIG. 8B is a block diagram illustrating a second exemplary framework within which applications are provided to end users according to one embodiment of the invention;

FIG. 8C illustrates an exemplary screenshot and usage of free cell selection with the configurable interactive producer output layout graphical user interface module **840** according to one embodiment of the invention;

FIG. 8D illustrates another exemplary screenshot and usage of free cell selection with the configurable interactive producer output layout graphical user interface module **840** according to one embodiment of the invention;

FIG. 8E illustrates an exemplary screenshot and usage of table creation with the configurable interactive producer output layout graphical user interface module **840** according to one embodiment of the invention;

FIG. 8F illustrates another exemplary screenshot and usage of table creation with the configurable interactive producer output layout graphical user interface module **840** according to one embodiment of the invention;

FIG. 9A is a block diagram illustrating a first scheme for distributing a runtime with producer graph oriented programming support according to one embodiment of the invention;

FIG. 9B is a block diagram illustrating a second scheme for distributing a runtime with producer graph oriented programming support according to one embodiment of the invention;

FIG. 9C is a block diagram illustrating a third scheme for distributing a runtime with producer graph oriented programming support according to one embodiment of the invention;

FIG. **10** is a block diagram of an exemplary implementation according to one embodiment of the invention;

FIG. **11**A is a block diagram of an example of the class tracking structure **1092** of FIG. **10** according to one embodiment of the invention;

FIG. **11**B is a block diagram of an example of the instance tracking structure **1065** of FIG. **10** according to one embodiment of the invention;

FIG. **11**C is a block diagram of an example of the producer graph(s) structure **1060** of FIG. **10** according to one embodiment of the invention;

FIG. **11**D is a block diagram of an example of the method tracking structure **1058** of FIG. **10** according to one embodiment of the invention;

FIG. **11**E is a block diagram of an example of a serialized form local map used in multiprocessing according to one embodiment of the invention;

FIG. **11**F is a block diagram of an example of a runtime setting structure **1048** of FIG. **10** according to one embodiment of the invention;

FIG. **11**G is a block diagram of an example of a producer-based configurable decision structure **1049** of FIG. **10** according to one embodiment of the invention;

FIG. **12**A is a block diagram illustrating additional detail of FIG. **10** to support multiprocessing according to one embodiment of the invention;

FIG. **12**B is a block diagram illustrating additional detail of FIG. **10** to support contingent and subscription type dynamic producer dependencies according to one embodiment of the invention;

FIG. **13**A illustrates pseudo code of producer dependency declarations for methods using a non-shortcut, non-dynamic (non-contingent, non-subscription) dependency according to one embodiment of the invention;

FIG. **13**B is a block diagram of producers illustrating an exemplary non-shortcut, non-dynamic (non-contingent, non-subscription) producer dependency according to one embodiment of the invention;

FIG. **13**C illustrates pseudo code of producer dependency declarations for methods using a non-shortcut, contingent, non-subscription producer dependency according to one embodiment of the invention;

FIG. **13**D is a block diagram of producers illustrating an exemplary non-shortcut, contingent, non-subscription producer dependency according to one embodiment of the invention;

FIG. **13**E illustrates pseudo code of producer dependency declarations for methods using both a non-shortcut, contingent, non-subscription producer dependency and a shortcut, contingent, non-subscription producer dependency according to one embodiment of the invention;

FIG. **13**F is a block diagram of producers illustrating a non-shortcut, contingent, non-subscription producer dependency and a shortcut, contingent, non-subscription producer dependency according to one embodiment of the invention;

FIG. **13**G illustrates pseudo code of producer dependency declarations for methods using a shortcut, contingent, non-subscription producer dependency and a shortcut, non-contingent, non-subscription producer dependency according to one embodiment of the invention;

FIG. **13**H is a block diagram of producers illustrating an exemplary shortcut, contingent, non-subscription producer dependency and a shortcut, non-contingent, non-subscription producer dependency according to one embodiment of the invention;

FIG. **13**I illustrates pseudo code of producer dependency declarations for methods using a shortcut, non-dynamic (non-contingent, non-subscription) producer dependency according to one embodiment of the invention;

FIG. **13**J is a block diagram of producers illustrating an exemplary shortcut, non-dynamic producer dependency according to one embodiment of the invention;

FIG. **14**A is a block diagram of an example of the subscription log 1250 of FIG. **12**B according to one embodiment of the invention;

FIG. **14**B is a block diagram of exemplary producers illustrating a non-contingent, absorbing subscription producer dependency according to one embodiment of the invention;

FIG. **14**C is a block diagram of exemplary producers illustrating a non-contingent, sticky subscription producer dependency according to one embodiment of the invention;

FIG. **14**D illustrates the choice of a parent producer based upon a parent dependency determination producer created by a sticky subscription according to one embodiment of the invention;

FIG. **14**E illustrates the choice of a parent producer based upon a parent dependency determination producer created by a child dependency determination producer, which child

dependency determination producer is linked by a sequencing dependency, according to one embodiment of the invention;

FIG. **15** is a flow diagram for instantiating new instances according to one embodiment of the invention;

FIG. **16**A is a flow diagram for instantiating new producers and unoverriding producers according to one embodiment of the invention;

FIG. **16**B is a flow diagram for block **1623** of FIG. **16**A according to one embodiment of the invention;

FIG. **17** is a flow diagram for block **1650** of FIG. **16**A according to one embodiment of the invention;

FIG. **18** is a flow diagram for block **1745** of FIG. **17** according to one embodiment of the invention;

FIG. **19** is a flow diagram for block **1630** of FIG. **16**A according to one embodiment of the invention;

FIG. **20** is a flow diagram for blocks **1635** and **1670** of FIG. **16**A according to one embodiment of the invention;

FIG. **21**A is a flow diagram for overriding producers according to one embodiment of the invention;

FIG. **21**B is a flow diagram for overriding producer execution mode settings according to one embodiment of the invention;

FIG. **21**C is a flow diagram for overriding execution mode settings globally at runtime level according to one embodiment of the invention;

FIG. **21**D is a flow diagram for overriding execution mode settings based on the producer-based configurable decision structure according to one embodiment of the invention;

FIG. **22**A is a part of a flow diagram for execution of the current producer graph(s) according to one embodiment of the invention;

FIG. **22**B is another part of a flow diagram for execution of the current producer graph(s) according to one embodiment of the invention;

FIG. **23** is a flow diagram for block **2205** of FIG. **22**A according to one embodiment of the invention;

FIG. **24** is a flow diagram for block **2260** of FIG. **22**B according to one embodiment of the invention;

FIG. **25** is a part of a flow diagram for execution of a set of ready producers substantially in parallel according to one embodiment of the invention;

FIG. **26** is another part of the flow diagram for execution of a set of ready producers substantially in parallel according to one embodiment of the invention;

FIG. **27**A is a part of a flow diagram for instantiating data structures before executing the set of ready producers according to one embodiment of the invention;

FIG. **27**B is another part of the flow diagram for instantiating data structures before executing the set of ready producers according to one embodiment of the invention;

FIG. **28**A is a flow diagram for executing producers using multithreading according to one embodiment of the invention;

FIG. **28**B is a flow diagram illustrating execution of a thread in multithreading according to one embodiment of the invention;

FIG. **28**C is a flow diagram for handling thread termination callback according to one embodiment of the invention;

FIG. **29**A is a part of a flow diagram for executing producers using multiprocessing and local execution according to one embodiment of the invention;

FIG. **29**B is another part of the flow diagram for executing producers using multiprocessing and local execution according to one embodiment of the invention;

FIG. **30** is a flow diagram for serializing inputs and/or an underlying instance of a producer to be multiprocessed according to one embodiment of the invention;

FIG. **31**A is part of a flow diagram for distant computing according to one embodiment of the invention;

FIG. **31**B is another part of the flow diagram for distant computing according to one embodiment of the invention; and

FIG. **32** is a flow diagram for local execution of producers according to one embodiment of the invention.

DETAILED DESCRIPTION

In the following description, numerous specific details such as logic implementations, opcodes, means to specify operands, resource partitioning/sharing/duplication implementations, types and interrelationships of system components, and logic partitioning/integration choices are set forth in order to provide a more thorough understanding of the invention. It will be appreciated, however, by one skilled in the art that the invention may be practiced without such specific details. In other instances, control structures, data structures, and full software instruction sequences have not been shown in detail in order not to obscure the invention. Those of ordinary skill in the art, with the included descriptions, will be able to implement appropriate functionality without undue experimentation.

Unless otherwise specified, dashed lines in the figures (with the exception of dashed dividing lines) are used to represent optional items in the figures. However, it should not be presumed that all optional items are shown using dashed lines, but rather those shown in dashed lines were chosen for a variety of reasons (e.g., they could be easily shown, to provide greater clarity, etc.).

References in the specification to "one embodiment", "an embodiment", "an example embodiment", etc., indicate that the embodiment described may include a particular feature, structure, or characteristic, but every embodiment may not necessarily include the particular feature, structure, or characteristic. Moreover, such phrases are not necessarily referring to the same embodiment. Further, when a particular feature, structure, or characteristic is described in connection with an embodiment, it is submitted that it is within the knowledge of one skilled in the art to affect such feature, structure, or characteristic in connection with other embodiments whether or not explicitly described.

In the following description and claims, the terms "coupled" and "connected," along with their derivatives, may be used. It should be understood that these terms are not intended as synonyms for each other. Rather, in particular embodiments, "connected" may be used to indicate that two or more elements are in direct physical or electrical contact with each other. "Coupled" may mean that two or more elements are in direct physical or electrical contact. However, "coupled" may also mean that two or more elements are not in direct contact with each other, but yet still co-operate or interact with each other.

In some cases, the operations of flow diagrams are described with reference to the exemplary embodiments of the other block diagrams. However, it should be understood that the operations of the flow diagrams can be performed by embodiments of the invention other than those discussed with reference to these other block diagrams, and that the embodiments of the invention discussed with reference to these other block diagrams can perform operations different than those discussed with reference to the flow diagrams.

The techniques shown in the figures can be implemented using code and data stored and executed on one or more computers. Such computers store and communicate (internally and with other computers over a network) code and data using machine-readable media, such as machine storage media (e.g., magnetic disks; optical disks; random access memory; read only memory; flash memory devices) and machine communication media (e.g., electrical, optical, acoustical or other form of propagated signals—such as carrier waves, infrared signals, digital signals, etc.). In addition, such computers typically include a set of one or more processors coupled to one or more other components, such as a storage device, a number of user input/output devices (e.g., a keyboard and a display), and a network connection. The coupling of the set of processors and other components is typically through one or more busses and bridges (also termed as bus controllers). The storage device and network traffic respectively represent one or more machine storage media and machine communication media. Thus, the storage device of a given computer system typically stores code and data for execution on the set of one or more processors of that computer. Of course, one or more parts of an embodiment of the invention may be implemented using different combinations of software, firmware, and/or hardware.

Overview

According to one aspect of the invention, a producer is at least a specific instance (or object) and a specific method, such that if the producer is executed during run time, the specific method is executed on the specific instance. Thus, a given producer is instantiated from a given instance and a given method associated with that instance. Like classes, instances, and methods, producers are basic elements or constructs manipulated by the runtime. Thus, the instantiation of a producer is interpreted and tracked by the runtime, and thus the runtime tracks the combination of instances and methods represented by producers. In other words, a producer is a runtime instantiatable construct that is tracked by the runtime, that is executed by the runtime, and that includes at least an instance and a method associated with that instance, such that the runtimes execution of the producer results in the method of the producer being executed on the instance of the producer. Also, the method of a producer has associated with it a producer dependency declaration that identifies, with a set of zero or more producer dependencies, a set of zero or more producers for the given producer. Specifically, producer dependencies are declared for methods using producer dependency declarations, the producer dependency declaration for a given method may include zero or more producer dependencies, and each producer dependency identifies a set of zero or more producers. Thus, producer dependency declarations and the producer dependencies they define are interpreted and tracked by the runtime, and thus the runtime tracks the relationships between producers indicated by the producer dependency declarations.

Where a given producer is dependent on a set of one or more other producers, the runtime will ensure execution of the set of other producers prior to the given producer. Thus, the producer dependency declarations represent execution relationships between producers, while producers represent operations to be performed (methods) and instances. While in some embodiments of the invention allow dependencies of parent producers on child producers to be declared in the producer dependency declaration associated with the method of the parent producer (the producer dependency declaration of the parent producer identifies any child producers—referred to herein as downwardly declared), other embodiments of the invention also allow dependencies to be declared in the producer dependency declaration associated with the method(s) of child producer(s) (the producer dependency declaration of the child producer identifies one or more parent producers—referred to herein as upwardly declared).

In different embodiments of the invention a producer identifies additional things. For example, while in some embodiments of the invention a producer is at least an instance and method associated with that instance, in other embodiments of the invention a producer is a class, an instance of that class, and a method associated with that instance (e.g., a producer may directly include a class, instance, and method; a producer may directly include an instance and a method, while indirectly identifying a class of that instance through a reference (e.g., a reference in the instance)). While the invention may be used in the context of code written in different programming languages (e.g., object-oriented code written in a reflective object-oriented language; object-oriented code written in a reflective object-based language; code written in a procedural, non-reflective object-oriented, non-reflective object-based language and transformed into reflective object-oriented language code), embodiments of the invention will be described, by way of example and not limitation, with reference to reflective object-oriented programming languages and with reference to producers that directly include classes, instances and methods. Also, while in one embodiment of the invention the method of a producer is an instance method (a method that can use instance fields in addition to any inputs received as arguments), alternative embodiments of the invention may also or alternatively support the method of a producer being a class method (methods that receive all inputs as arguments and/or uses instance independent variables) (where the method of a producer is an instance method, the instance of that producer is an instance of a class; while where the method of a producer is a class method, the instance of that producer is a meta-class instance representing the class).

FIG. **1**A is a block diagram illustrating the relationship of a producer dependency declaration for a method of a class in object oriented-source code to a producer that includes the class, a given instance of that class, and a method of that class, according to one embodiment of the invention. In FIG. **1**A, object-oriented source code **100** is shown including a class **102**, which in turn includes a method **104**, execution mode settings **105**, and a producer dependency declaration **106** for the method **104**. Of course, the class **102** would typically include one or more fields (not shown) and additional methods (not shown). In addition, the object-oriented source code **100** would typically include additional classes.

During run time, an instance **108** of the class **102** is instantiated. The instance **108** includes the data of the fields of the class **102**. In addition, a producer **110** is instantiated, where the producer **110** identifies the class **102**, the instance **108** of the class **102** (which has associated with it the method **104** of the class **102**), and the method **104** of the class **102**. The producer dependency declaration **106** identifies to the runtime a set of zero or more producers **112** (referred to as child producers of the producer **110**) that must be executed before execution of the producer **110**. In other words, the producer **110** depends on the set of zero or more producers **112**. In addition to or instead of consuming outputs of the set of producer **112**, the producer **110** may consume data of the instance **108**. In addition, the producer **110** provides at least one output, which output may be internal to the instance **108** (and thus, modify the data of the instance **108**) and/or may be external; either way, the output of the producer **110** may be consumed by a set or zero or more other producers **114** (referred to as parent producers of the producer **110**)). As

indicated previously, and described in more detail later herein, the producer dependency declaration **106**, in some embodiments of the invention, may also identify to the runtime zero or more of the producers **114**.

It should be understood that the inputs and outputs of producers are based on the inputs and outputs of the methods on which those producers are based. As such, these input and outputs may represent multiple parameters having a variety of data structures.

The producer dependency declaration for a given method identifies at run time the set of zero or more producers to be instantiated and executed. By way of example, where a producer dependency declaration (e.g., producer dependency declaration **106**) for a given method (e.g., method **104**) identifies a producer dependency on a given producer (which given producer identifies a first class, a first instance of that class, and a first method of that first class) (e.g., one of the set of producers **112**), then the producer dependency declaration of the given method identifies to the runtime that the first instance is to be instantiated (if not already) and that the first method is to be used to instantiate the given producer for the first instance (in these examples, first does not mean location or order).

In operation, when, during run time, a given set of one or more producers are designated as being of interest and have producer dependencies declared for them, the runtime: 1) automatically generates (discovers, builds, and optionally resolves) a set of one or more graphs, which may be multi-level and may be of a variety of shapes (e.g., chain, tree), from the given set of producers designated as being of interest down to source producers based on the producer dependency declarations **106**; and 2) sequences execution of producers of the set of graphs to generate the output(s) of the given set of producers designated as being of interest. Thus, the runtime uses the producer dependency declarations **106** to determine what methods with what arguments to execute, on what instances, and when for synchronization purposes.

In some embodiments, the runtime checks the execution mode setting **105** to determine the execution mode of a producer. Different execution modes may be supported in different systems. Some examples of execution modes include multithreading, multi-processing, and local execution.

Producer dependencies represent the sequencing of execution of producers to the runtime. However, in addition to indicating the sequencing of execution, producer dependencies may represent different input to output relationships in different embodiments of the invention. For example, different embodiments of the invention may support one or more of argument producer dependencies, field producer dependencies, and sequencing only producer dependencies (sequencing only producer dependencies are referred to herein with the shorthand sequencing producer dependencies). While each of argument producer dependencies, field producer dependencies, and sequencing producer dependencies represent execution sequencing relationships between producers, argument and field producer dependencies additionally represent data of which the runtime is aware. Specifically, an argument producer dependency causes the runtime to map the output of a child producer as an input parameter to a parent producer, whereas a field producer dependency indicates use of a field of an instance. Regardless of the input to output relationship represented by a producer dependency, proper use of producer dependencies ensures that the producers accessing information are sequenced after the producers that impact that information.

Sequencing dependencies may be used for a variety of purposes, including ensuring the order of execution between producers that modify data in a manner of which the runtime is not aware and producers that consume that data (a child producer may write its outputs in a way that requires the method of the parent producer to include code to access that output (e.g., a method that impacts the environment by affecting an output that is not the regular producer output and, as such, that is not detected by the runtime—such as a method that sets a global variable, that sets a field in an instance which is not the producer output, that impacts an external data source, etc.)) Thus, a sequencing dependency reflects a dependency of a parent producer on a child producer, but requires outputs that need to be provided, if any, from one to the other occur through the writing of code (e.g., code in the method of the child producer to write an output to a given mechanism (such as set a global variable, impact an external data source, set a field of an instance which is not the producer output, etc.) and code in the method of the parent producer to read that output from the given mechanism). In this way, sequencing dependencies allow the runtime to synchronize execution of any parent producers that rely on an output that the runtime cannot detect.

In one embodiment of the invention the producer dependency declaration **106** for a given method identifies only direct dependencies on producers (e.g., direct descendents (children), in contrast with indirect descendents (grand-children, great grand-children, etc.)). In such an embodiment, each producer dependency declaration provides only a single tier or layer of producers whose outputs may be used directly by a producer instantiated from the given method; leaving discovery/building/resolution of additional layers of the producer graph(s) to the runtime's processing of other producer dependency declarations.

According to one embodiment of the invention, the dependencies of producers identified by the producer dependency declaration **106** are useful in implementing parallelization and instrumentation of the application program including the producers. To parallelize the application program, two or more producers of the application program are executed substantially at about the same time in the same execution mode or in different execution modes. To instrument the application, metrics of the producers are acquired as the producers are being executed. Details of parallelization and instrumentation are further discussed below with reference to exemplary embodiments of the invention.

Exemplary Keys

A producer can be viewed as a set of multiple identifiers, one identifier for each additional level of granularity specified (class, instance, method, etc.). In addition, some embodiments of the invention implement each identifier as a separate key, while other embodiments have certain identifiers share a key. By way of example, some embodiments of the invention implement a producer as a class, instance, and method triplet and implement keys, such that each part of the triplet is identified by a separate key (a class key, instance key, and method key) and the producer is identified by the combination of the class key, instance key, and method key (the producer key).

Embodiments of the invention that use keys may vary in the uniqueness of the keys used. For example, in one embodiment of the invention, each class key is unique, each instance key is unique across all instances of all classes, and each method key is unique across all methods of all classes. As another example, in other embodiments of the invention, each class has a unique key, each instance of a given class has a unique key (across the class instances), and each method of a class has a unique key (across the class methods); but instances of different classes may have the same instance key, and meth-

ods of different classes may have the same method key; this later approach will be used in the remainder of the document by way of example and not limitation. For example, assume a first class includes methods and has a key for each of these methods that is unique within the first class, then the instances of this class (which will each have a unique key as to each other) have the same method keys associated with them. As another example, assume a different second class includes methods (be some, all, or none the same as the methods of the first class) that have the same method keys as those used for the first class; as such, an instance of this different class may have associated with it the same method keys as associated with an instance of the first class.

The use of keys allow for a variety of features, including: 1) the tracking of each entity identified by a producer's identifiers (e.g., the tracking of each class, instance, and method); 2) several parent producers (unaware of their mutual existence) to connect to the same child producer based on their producer dependency declarations (which specify producer dependencies using the producer keys); etc. In one embodiment of the invention, the instance key is an instance of a class (InstanceKey) holding two elements: an instance key nature indicating if the key identifier is a reference to the instance or another object (such as a string), and a key identifier which can either be a reference to the instance, or another object (such as a string). The storing of an instance reference in the instance key spares the programmer from inventing a name to identify these instances.

Exemplary Relationships

In the context of the above discussion regarding a producer being viewed as a set of multiple identifiers (with one identifier for each additional level of granularity specified), in one embodiment of the invention the various supported relationships between a producer and its children and parents are those in which at least one such identifier is different between a producer and its set of zero or more parent producers and one such identifier is different between a producer and each of its set of zero or more child producers. By way of providing some exemplary relationships, assume that a first producer is instantiated, where the first producer is a first instance of a first class and a first method of that first class, and assume that the producer dependency declaration for that first method identifies at run time a second producer as a child, then the second producer may be: 1) the first instance of the first class and a second method of that first class; 2) a second instance of the first class and a second method of that first class; or 3) a second instance of the first class and the first method of the first class; or 4) an instance of a second class and a method of that second class. In such case, the first producer is dependent on the second producer—thus, representing an input to output relationship of the first producer on the second producer. Various relationships and combinations of those relationships are described below for one embodiment of the invention that uses an object-oriented language and in which a producer identifies at least a class, instance, and method.

FIGS. **1**B-**1**D illustrate exemplary relationships between a given producer, its set of parent producers, and its set of child producers according to one embodiment of the invention. FIGS. **1**B-**1**D each show the following: 1) a class definition **102**A including methods **104**A-C and producer dependency declarations **106**A-C for each of those methods, respectively; 2) a class definition **102**B including methods **104**D-E and producer dependency declarations **106**D-E for each of those methods, respectively; 3) a class definition **102**C including method **104**F and producer dependency declaration **106**F for that method; 4) an instance **108**A of the class **102**A; 5) a producer **110**A that identifies the class **102**A, the instance **108**A, and the method **104**A; and 6) a producer **112**A.**1** and a producer **114**A.**1** respectively representing one of the set of producers **112** and **114**. Dashed lines with boxed letters on them are used in FIGS. **1**B-**1**D to illustrate the exemplary relationships. Thus, the collection of dashed lines with a boxed A on them represent one relationship. The relationships in FIG. **1**B are combinable with the relationships in FIG. **1**C; as such, these combinations represent combinations of relationships between parent producers **114**A and child producers **112**A to producer **110**A. Further, FIG. **1**D illustrates some additional exemplary combinations of relationships between parent producers **114**A and child producers **112**A to producer **110**A.

FIG. **1**B illustrates exemplary relationships between the producer **110**A and the parent producer **114**A.**1** according to one embodiment of the invention. FIG. **1**B additionally includes an instance **108**B. The set of producers **114** is identified by other producer dependency declarations of different method(s) of the same class, different instances of the same class, and/or method(s) of a different class; and thus, each of the set of producers **114** may be: 1) of the same instance as the producer **110**A (instance **108**A of class **102**A) and a different method of that instance (illustrated by the boxed A on the dashed lines from the instance **108**A to the producer **114**A.**1** and from the method **104**B to the producer **114**A.**1**); 2) of a different instance of the class **102**A and a different method of that instance (illustrated by the boxed B on the dashed lines from the class **102**A to the instance **108**B, from the instance **108**B to the producer **114**A.**1**, and from the method **104**B to the producer **114**A.**1**); 3) of an instance of a different class and a method of that instance (illustrated by the boxed C on the dashed lines from the class **102**B to the instance **108**B, from the instance **108**B to the producer **114**A.**1**, and from the method **104**D to the producer **114**A.**1**); or 4) of a different instance of class **102**A (than instance **108**A) and the same method (method **104**A) of that instance (e.g., with a contingent dependency—described later herein) (illustrated by the boxed D on the dashed lines from the class **102**A to the instance **108**B, from the instance **108**B to the producer **114**A.**1**, and from the method **104**A to the producer **114**A.**1**); further, where there are multiple producers in the set of producers **114**, the producers **114** themselves may be part of the same instance of the class **102**A, different instances of the class **102**A, the same instance of a different class, different instances of a different class, and/or a mixture of the above.

FIG. **1**C illustrates exemplary relationships between the producer **110**A and the child producer **112**A.**1** according to one embodiment of the invention. FIG. **1**C additionally includes an instance **108**C. Each of the set of producers **112**A may be: 1) of the same instance as the producer **110**A (instance **108**A of class **102**A) and a different method of that instance (illustrated by the boxed E on the dashed lines from the instance **108**A to the producer **112**A.**1** and from the method **104**C to the producer **112**A.**1**); 2) of a different instance of the class **102**A and a different method of that instance (illustrated by the boxed F on the dashed lines from the class **102**A to the instance **108**C, from the instance **108**C to the producer **112**A.**1**, and from the method **104**C to the producer **112**A.**1**); 3) of an instance of a different class and a method of that instance (illustrated by the boxed G on the dashed lines from the class **102**C to the instance **108**C, from the instance **108**C to the producer **112**A.**1**, and from the method **104**F to the producer **112**A.**1**); or 4) of a different instance of class **102**A (than instance **108**) and the same method (method **104**A) of that instance (e.g., with a contingent dependency described later herein) (illustrated by the boxed H on the dashed lines from the class **102**A to the

instance **108**C, from the instance **108**C to the producer **112**A.**1**, and from the method **104**A to the producer **112**A.**1**). Thus, each of the set of producers **112**A may be of the same instance as the producer **110**A, of a different instance of the class **102**A, or an instance of a different class; further, where there are multiple producers in the set of producers **112**A, the producers **112**A themselves may be part of the same instance of the class **102**A, different instances of the class **102**A, the same instance of a different class, different instances of a different class, and/or a mixture of the above.

FIG. **1**D illustrates some additional exemplary combinations of relationships of parent producers **114** and child producers **112** to producer **110**A according to one embodiment of the invention. FIG. **1**D additionally includes the instance **108**B and the instance **108**C. The combinations of FIG. **1**D are shown in Table 1 below:

TABLE 1

Boxed Letter	Dashed Lines For Parent Producer 114A.1 from	Dashed Lines For Child Producer 112A.1 from
I	From instance 108A to producer 114A.1 and from method 104B to producer 114A.1	From instance 108A to producer 112A.1 and from method 104B to producer 112A.1
J	From instance 108A to producer 114A.1 and from method 104B to producer 114A.1	From class 102A to instance 108C, from instance 108C to producer 112A.1, and from method 104B to producer 112A.1
K	From class 102A to instance 108B, from instance 108B to producer 114A.1, and from method 104B to producer 114A.1	From instance 108A to producer 112A.1 and from method 104B to producer 112A.1
L	From class 102B to instance 108B, from instance 108B to producer 114A.1, and from method 104E to producer 114A.1	From class 102B to instance 108B, from instance 108B to producer 112A.1, and from method 104E to producer 112A.1
M	From class 102B to instance 108B, from instance 108B to producer 114A.1, and from method 104E to producer 114A.1	From class 102B to instance 108C, from instance 108C to producer 112A.1, and from method 104E to producer 112A.1
N	From class 102A to instance 108B, from instance 108B to producer 114A.1, and from method 104A to producer 114A.1	From class 102A to instance 108C, from instance 108C to producer 112A.1, and from method 104A to producer 112A.1
O	From class 102A to instance 108B, from instance 108B to producer 114A.1, and from method 104A to producer 114A.1	From class 102A to instance 108B, from instance 108B to producer 112A.1, and from method 104A to producer 112A.1
P	From instance 108A to producer 114A.1 and from method 104B to producer 114A.1	From class 102A to instance 108C, from instance 108C to producer 112A.1, and from method 104A to producer 112A.1
Q	From class 102A to instance 108B, from instance 108B to producer 114A.1, and from method 104A to producer 114A.1	From class 102A to instance 108B, from instance 108B to producer 112A.1, and from method 104B to producer 112A.1
R	From class 102B to instance 108B, from instance 108B to producer 114A.1, and from method 104D to producer 114A.1	From class 102B to instance 108B, from instance 108B to producer 112A.1, and from method 104E to producer 112A.1

FIG. **1**E illustrates that different instances of the same class can have producers based on the same and/or different methods according to one embodiment of the invention. FIG. **1**E shows: 1) the class definition **102**A including methods **104**A-C and producer dependency declarations **106**A-C for each of those methods, respectively; 2) the instance **108**A and the instance **108**B being of class **102**A; 3) a producer **110**A is the method **104**A of the instance **108**A of the class **102**A; 4) a producer **110**B is the method **104**B of the instance **108**A of the class **102**A; 5) a producer **110**C is the method **104**A of the instance **108**B of the class **102**A; and 6) a producer **110**D is the method **104**C of the instance **108**B of the class **102**A. In addition, FIG. **1**D shows that: 1) the producer dependency declaration **106**A for method **104**A identifies at run time the child producers of both the producer **110**A and the producer **110**C; 2) the producer dependency declaration **106**B for method **104**B identifies at run time the child producer of producer **110**B; and 3) the producer dependency declaration **106**C for method **104**C identifies at run time the child producer of producer **110**D.

Exemplary Runtimes

FIG. **2** is a block diagram illustrating the reusability of a runtime with producer graph oriented programming support according to one embodiment of the invention. In FIG. **2**, multiple object-oriented application programs (object-oriented application code with producer dependency declarations **210**A-I) are run by the same runtime with producer graph oriented programming support **220**.

FIG. **3**A is a block diagram illustrating a runtime with producer graph oriented programming support according to one embodiment of the invention. In FIG. **3**A, a runtime with producer graph oriented programming support **335** includes an automated producer graph generation module **340** and a producer graph execution module **345**. In addition, the runtime **335** is to execute object-oriented source code, and thus includes additional modules not shown.

In addition, FIG. **3**A shows producer dependency declarations for methods in object-oriented source code **320**, a current set of one or more producers whose outputs are of interest **325** (also referred to here as the currently selected producers of interest), and the outputs of source producers **330** (described later herein). The automated producer graph generation module **340** receives the producer dependency declarations **320** and the current set of producers of interest **325**.

The automated producer graph generation module **340** attempts to discover, based on the producer dependency declarations, child producers with outputs that contribute directly and indirectly to the input of the currently selected producers of interest, and build a current graph of producers representing the input dependency of these producers on each other from the currently selected producers of interest to those of the discovered producers that are source producers. The producer graphs(s) are stored in the producer graph(s) structure **380**.

The producer graph execution module **345** receives the current producer graph(s) from the automated producer graph generation module **340** and the outputs of source producers **330**, and executes the producers of the current producer graph(s) to determine the current output of the currently selected producers of interest. In some embodiments, the producer graph execution module **345** includes a parallelization module **3451**, a multiprocessing module **3453**, a multithreading module **3455**, and a local execution module **3457**. The parallelization module **3451** may determine the execution mode of a producer and send the producer to one of the multiprocessing module **3453**, the multithreading module **3455**, and the local execution module **3457** to be executed in the execution mode determined Parallelization may be supported by an individual execution mode. For instance, parallel execution of producers may be accomplished by the multiprocessing module **3453** using multiprocessing. Alternatively, parallel execution of producers may be accomplished by the multithreading module **3455** using multithreading. Furthermore, parallelization may be supported by a combination of execution modes. In other words, producers may be executed in parallel using different execution modes. For instance, two producers may be executed in parallel by sending one producer to the multithreading module **3455** and the other producer to the local execution module **3457**. It should be appreciated that other combinations of execution modes may be used to implement parallelization.

The producer graph execution module **345** caches the current outputs of the producers in the producer graph structure **380** as illustrated by the producer output caching **384**. The caching of producer outputs of the producer graph during execution allows for synchronization. For instance, the appropriate time to execute a parent producer that is dependent on multiple child producers is after all of the multiple child producers have been executed; in other words, it would be wasteful (and, in some cases, not possible) to execute the parent producer each time one of its child producers completed execution. The caching of the producer outputs allows for the execution of the parent producer to not only be postponed until all its child producers have been executed, it also allows for a determination of the appropriate time for the execution of the parent producer—when all of the child producers have been executed and their outputs have been cached. Thus, the runtime makes this synchronization decision for the programmer by checking the availability of the needed outputs in the producer output caching **384**; in other words, such synchronization is automated (the programmer need not include separate source code that determines the appropriate time to execute a given method of an instance). By way of another example, where several parent producers are dependent on the same child producer as well as on other different child producers, the appropriate time to execute each of the several parent producers is typically different; the runtime automatically determines the appropriate time to execute each of the several parent producers depending on the availability of the outputs of its set of child producers.

As will be described in more detail later herein, since some parts of a producer graph may not be currently discoverable due to dynamic producer dependencies, the automated producer graph generation module **340** "attempts" to discover and build the entire producer graph, but may not initially be able to complete the entire producer graph until some producers are executed. As such, the producer graph execution module **345** may invoke the automated producer graph generation module **340** with needed producer outputs during execution of the current producer graph to complete any unresolved remainders of the current producer graph (this is illustrated in FIG. **3**A by a dashed arrowed line from the producer graph execution module **345** to the automated producer graph generation module **340**; a dashed arrowed line is used because such support is optional)

FIG. **4**A is a block diagram illustrating the discovery and building of an exemplary producer graph according to one embodiment of the invention. FIG. **4**A shows that the current set of producers of interest consists of producer **1**. Based upon producer **1** and its producer dependency declaration, producer **2** and producer **3** are discovered. In other words, the producer dependency declaration for producer **1** identifies that the input to producer **1** requires execution of producer **2** and producer **3**. As such, producer **1** is a dependent producer (a producer that has one or more producer dependencies). FIG. **4**A also shows that while producer **3** is an independent producer (a producer that has no producer dependencies, and thus is a source producer), producer **2** is not. As a result, based upon the producer dependency declaration of producer **2**, producer **4** and producer **5** are discovered. In FIG. **2**A, producer **4** and producer **5** are independent producers (and thus, source producers).

FIG. **4**B is a block diagram illustrating the initial execution of the producer graph of FIG. **4**A according to one embodiment of the invention. In FIG. **4**B, curved arrowed lines illustrate the execution of one producer to generate an output that is provided as the input to another producer. As shown in FIG. **3**A, the output of the source producers **330** are provided to the producer graph execution module **345**; in contrast, the outputs of the dependent producers **1**-**2** are determined by execution of those producers as shown in FIG. **4**B. Thus, in FIG. **4**B, the following occurs: 1) the output of source producer **4** and source producer **5** are provided to dependent producer **2**; 2) dependent producer **2** is executed; 3) the outputs of dependent producer **2** and source producer **3** are provided to producer **1**; and 4) producer **1** is executed and its output is provided as the current output of interest. It is worth noting that the producer graph of FIG. **4**B is data driven in the sense that data flows from one producer to another producer up the graph.

In some embodiments, producer **4** and producer **5** may be executed in parallel using different execution modes or a single execution mode that supports parallelization (e.g., multiprocessing, multithreading, etc.) because producer **4** and producer **5** are independent of each other. However, since producer **2** depends on producers **4** and **5** in the current example, producer **2** may not be executed in parallel with producers **4** and **5**. Thus, the runtime may wait for producers **4** and **5** to be done before executing producer **2**. As for producer **3**, since producer **3** is independent of producers **4** and **5**, producer **3** may be executed in parallel with producers **4** and **5**. Alternatively, producer **3** may be executed in parallel with producer **2** because producer **3** is also independent of producer **2**. In some embodiments, execution of producer **3** may overlap in time with the execution of producers **4** and **5**, as well as the execution of producer **2**, depending on how long it takes to execute producers **3**, **4**, and **5**.

Thus, the producer dependency declarations **320** bound the possible producer graphs that may be generated; while the currently selected set of producers of interest **325** identify the beginning node(s) of the current producer graph to be generated. From these two, the automated producer graph generation module **340** discovers and builds the producer graph. The discovery and building is automated in that the automated producer graph generation module **340** is not provided the producer graph (e.g., it does not need to be manually identified by a programmer) or even a list of the producers that will be in the producer graph. Rather, the automated producer graph generation module **340** parses the producer dependency declaration(s) of the current selected set of producers of interest to discover their discovered producers, then parses the producer dependency declarations of those discovered producers, and so on down to the source producers (in some embodiments of the invention described later herein, this may be done with the assistance of the producer graph execution module **345**). In the case where the producer graph is a tree, a currently selected producer of interest will typically be the root node, and the producer dependency declarations will be parsed until the leaf nodes (source producers) are discovered.

Overridden Producers and Incremental Execution

FIG. **3**B is a block diagram illustrating a runtime with producer graph oriented programming support that also supports incremental execution and overridden producer outputs according to one embodiment of the invention. It should be understood that incremental execution and overridden producer outputs are each independent optional features, and thus different embodiments of the invention may implement one or both. Although not explicitly illustrated in FIG. **3**B, one should appreciate that the parallelization modules **3451**, the multiprocessing module **3453**, the multithreading module **3455**, and the local execution module **3457** in FIG. **3**A may be included in the producer graph execution module **370** in FIG. **3**B to allow the producer graph execution module **370** in FIG. **3**B to implement parallelization in the execution of producers.

In FIG. **3**B, a runtime with producer graph oriented programming support **360** includes an automated producer graph generation module **365**, a producer graph execution module **370**, and an override producer output module **390**. The runtime **360** is to execute object-oriented source code, and thus includes additional modules not shown.

In addition, FIG. **3**B shows the producer dependency declarations for methods in object-oriented source code **320**, the current set of one or more producers whose outputs are of interest **325** (also referred to herein as the currently selected producers of interest), and the output of source producers **350**. The output of source producers **350** includes the outputs of independent producers set in the source code **352** (e.g., constants, default values, etc.) and the currently overridden producer outputs **354** (the outputs of the independent producers and/or dependent producers whose outputs are currently overridden).

In some embodiments of the invention, the outputs of producers may be explicitly overridden with a currently provided value (i.e., rather than executing a producer to determine its output value based on its current inputs, the output value for the producer is explicitly provided). In addition to any independent producers of a producer graph, the source producers of a producer graph include any currently overridden producers.

The override producer output module **390** receives the overridden producer outputs **354** (which identify which producers are being overridden and what output values they are being overridden with). In one embodiment of the invention, producers can be classified as property producers or method producers. Property producers are those based on property methods (e.g., get and set). Method producers are those based on non-property methods. The override producer output module **390** includes an override property producer output module **392** for overridden property producers and an override method producer output module **394** for overridden method producers. The override property producer output module **392** causes the overridden value to be stored in the producer output caching **384** and in the data of the instance, whereas the override method producer output module **394** causes the overridden value to be stored in the producer output caching **384**. Depending on the embodiment of the invention, this causation may be direct or indirect. FIG. **3**B illustrates an indirect causation through the use of an override log **396** which collects the output of the override producer output module **390** and which is consumed by the producer graph execution module **370**. For optimization purposes, the override log **396** allows for the delaying of overrides in order to collect multiple overrides for batch processing.

Similar to the automated producer graph generation module **340**, the automated producer graph generation module **365**: 1) receives the producer dependency declarations **320** and the current set of producers of interest **325**; and 2) attempts to discover, based on the producer dependency declarations, producers with outputs that contribute directly and indirectly to the input of the currently selected producers of interest, and build a current graph of producers representing the input dependency of these producers on each other from the currently selected producers of interest, through any discovered non-source producers, to those of the discovered producers that are source producers (independent producers and currently overridden producers). The producer graphs(s) are stored in the producer graph(s) structure **380**.

Similar to the producer graph execution module **345**, the producer graph execution module **370** receives the current producer graph from the automated graph module **365** and the outputs of source producers **350**, and executes the producers of the current producer graph to determine the current output of the currently selected producers of interest. The producer graph execution module **370** caches the current outputs of the producers in the producer graph structure **380** as illustrated by the producer output caching **384**.

As previously described, the caching of producer outputs during execution allows for synchronization (e.g., separate source code need not be written to determine when producer **2** of FIG. **4**B should be executed, but rather the runtime makes this synchronization decision for the programmer by checking the availability of the needed outputs in the producer output caching **384**; in other words, such synchronization is automated). Furthermore, the caching of producer outputs during execution may allow parallelization of producer execution because the runtime may decide which producer is ready for execution by checking the availability of the needed outputs in the producer output caching **384**. Producers that are ready for execution may be executed in parallel. In other words, parallelization may be automated as well. Thus, no separate source code is needed to determine or to indicate which producers should be executed in parallel. In addition, this producer output caching **384** is used for incremental execution. More specifically, after a producer graph has been initially generated and executed, the overriding of a producer in the current producer graph requires some level of reexecution. While some embodiments of the invention simply reexecute the entire graph, alternative embodiments of the invention support incremental execution (reexecuting only those parts of the producer graph that are affected by the override).

Some exemplary embodiments that support incremental execution use incremental execution marking **382** in the producer graph(s) structure **380** to help determine which producers require reexecution. Thus, maintaining the producer graph refers to modifying the links of the producer graph as necessary across multiple executions, to keep them current (up to date), whereas incremental execution refers to both maintaining the producer graph(s) and using the current (up to date) producer graph(s) to re-execute only those parts of the producer graph(s) that are affected by an override.

Similar to FIG. **3**A, there is a dashed arrowed line from the producer graph execution module **370** to the automated producer graph execution module **365** to represent optional support for dynamic dependencies. It should be noted that dynamic dependencies may change during reexecution of a producer graph.

FIG. **4**C is a block diagram illustrating the incremental execution of the producer graph of FIG. **4**B according to one embodiment of the invention. In FIG. **4**C, the output of producer **5** has been explicitly modified, but the outputs of producer **3** and producer **4** have not. Based upon the tracking of output to input dependencies in the producer graph and that only the output of producer **5** has been explicitly modified, it is determined that only producer **2** and producer **1** are affected by this modification. As a result, the determination of an updated output of producer **1** requires only the reexecution of producer **2** and producer **1** with the new output of producer **5** and the prior outputs of producer **4** and producer **3**. This partial reexecution of the producer graph is illustrated in FIG. **4**C by curved arrowed lines from producer **5** to producer **2** and from producer **2** to producer **1**, but not from producer **4** to producer **2** or from producer **3** to producer **1**. The lack of curved arrowed lines from producer **4** to producer **2** and from producer **3** to producer **1** are not to indicate that the outputs of producer **3** and producer **4** are not needed, but rather that producer **3** and producer **4** need not be reexecuted if their prior output is available. (e.g., cached from the prior execution of the producer graph).

The relatively simple example of FIG. **4**C illustrates that there can be a savings in processing resources as a result of incremental execution. Such savings depend on a number of factors (e.g., the number of producers that do not need to be reexecuted, the amount of processing those producers would have required, etc.). While one embodiment of the invention is illustrated that performs incremental execution, alternative embodiments may be implemented differently (e.g., an alternative embodiment may reexecute all producers responsive to a modification).

FIG. **4**D is a block diagram illustrating the incremental execution of the producer graph of FIG. **4**B after dependent producer **2** has been overridden according to one embodiment of the invention. In FIG. **4**D, the output of producer **2** has been explicitly modified, but the output of producer **3** has not. Based upon the producer graph and that only the output of producer **2** has been explicitly modified, it is determined that only producer **1** is affected by this modification. As a result, the determination of an updated output of producer **1** requires only the reexecution of producer **1** with the overridden output of producer **2** and the prior output of producer **3**. This partial reexecution of the producer graph is illustrated in FIG. **4**D by a curved arrowed line from producer **2** to producer **1**, but not from producer **4** and **5** to producer **2** or from producer **3** to producer **1**.

FIG. **4**E is a block diagram illustrating the incremental execution of the producer graph of FIG. **4**B after dependent producer **2** has been overridden and independent source producer **3** has been modified according to one embodiment of the invention. Based upon the producer graph and that only the outputs of producer **2** and producer **3** have been modified, it is determined that only producer **1** is affected by this modification. As a result, the determination of an updated output of producer **1** requires only the reexecution of producer **1** with the overridden output of producer **2** and the modified output of producer **3**. This partial reexecution of the producer graph is illustrated in FIG. **4**E by a curved arrowed line from producers **2** and **3** to producer **1**, but not from producers **4** and **5** to producer **2**.

While one embodiment of the invention that supports overriding producer outputs also supports unoverriding producer outputs, alternative embodiments of the invention do not. While one embodiment of the invention that supports unoverriding producers leaves an overridden producer overridden until it is specifically unoverridden, alternative embodiments of the invention may be implemented differently (e.g., unoverriding an overridden producer when one of its progeny is overridden).

In one embodiment of the invention the producer graph oriented programming framework includes an external interface used to interface with programs not written with producer dependency declarations. This external framework includes: 1) a caller part (referred to as the runtime client); and 2) a called part (referred to as an external data source). If a producer reads data directly from an external data source, it may just read the data when the producer is created, just read the data when instructed to do so (manual refresh), or subscribe to it. In the case of manual refresh and subscription, changes in the external data source would result in the set method of the producer being invoked and the modification of the output of the producer (treated the same as an overridden producer).

Producer Graph Building and Execution

Different embodiments of the invention may be implemented to discover and build out a producer graph to different extents (e.g., build the producer graph until all paths from the root node end at independent producers (in which case, the end nodes of a producer graph are independent producers, with the possibility of any overridden producers being intermediate nodes); build the producer graph out until each path from the root node ends in an overridden producer or an independent producer, whichever is reached first (in which case, each end node of a producer graph is either an independent producer or an overridden producer)).

"Execution start producers" refers to the producers of a producer graph from which a given execution of the producer graph begins. For an initial execution of a producer graph, different embodiments may start from different producers (e.g., in embodiments of the invention that build the producer graph until all paths from the root node end at independent producers, execution may start from the end nodes (which would be the independent producers), from the source producers (which would include the independent producer nodes and any overridden producer nodes), from a subset of the source producers consisting of the combination of any independent producers with at least one path between them and the root producer that does not include an overridden producer and any overridden producers, or from a subset of the source producers consisting of the combination of any overridden producers without any descendents that are overridden and any independent producers with at least one path between them and the root producer that does not include an overridden producer; in embodiments of the invention where the producer graph under overridden producers is not built if and until such a producer is un-overridden, execution may start

from the end nodes (which may be independent producers and/or overridden producers), etc).

For subsequent executions of a producer graph, different embodiments may start from different producers (e.g., from the independent producers of the producer graph (e.g., in embodiments of the invention that do not support incremental execution); from the source producers of the producer graph (e.g., in embodiments of the invention that do not support incremental execution); from a subset of the source producers that consists of those source producers that have been overridden and/or added since the last execution (e.g., in embodiments of the invention that do support incremental execution); of the source producers that have been overridden and/or added since the last execution, from the combination of any such overridden producers without any descendents that are overridden and any such added producers with at least one path between them and the root producer that does not include an overridden producer (e.g., in embodiments of the invention that do support incremental execution); etc).

With regard to the above concept of execution start producers, the processing flow of execution of the producer graph also differs between different embodiments. For example, in one embodiment of the invention, the ancestry of the execution start producers are determined and placed in a collection, the execution start producers are executed, and the collection is iteratively scanned for producers for whom all dependencies have been executed—eventually the root nodes are reached. As another example, in one embodiment of the invention, the execution start producers are executed, the parents of the execution start producers are identified, those parents are executed, and their parents are identified and executed, and so on. The later embodiment of the invention is used below by way of example, and not limitation.

Exemplary Types of Dependencies

Exemplary Dynamic Producer Dependencies

A dynamic producer dependency is a producer dependency that can change during run time. It should be understood that the criteria for resolving the producer dependency is present in the source code, and thus the producers to which the producer dependency may be resolved are limited. With reference to FIG. **3**A, the dashed arrowed line from the producer graph execution module **345** to the automated producer graph generation module **340** represents support for the execution of one or more producers in the current producer graph that are necessary to discover and build the entire current producer graph. In other words, an embodiment of the invention that supports dynamic producer dependencies may iterate between the automated producer graph generation module **340** and the producer graph execution module **345** until the entire producer graph is discovered, built, resolved, and executed (that is, iterate between: 1) invoking the automated producer graph generation module to discover and build those parts of the current producer graph that can be resolved at that time; and 2) invoking the producer graph execution module to execute producers of the current producer graph). In this sense, discovering refers to the accessing of the producer dependency declarations and determining the producers they identify; building refers to instantiating the producers and adding them to the producer graph; and resolving refers to determining currently unresolved dynamic producer dependencies.

FIG. **5**A is a block diagram illustrating the discovery and building of an exemplary producer graph including an unresolved dependency according to one embodiment of the invention. FIG. **5**A shows the current set of producers of interest consisting of producer **1**. Based upon producer **1** and its producer dependency declaration, producer **2** and producer **3** are discovered. In other words, the dependency declaration for producer **1** identifies that producer **1** requires as inputs the output of producer **2** and producer **3**. FIG. **5**A also shows that while producer **3** is an independent producer (and thus, a source producer), producer **2** is not. As a result, based upon the dependency declaration of producer **2**, producer **4** and producer **5** are discovered. Further, FIG. **5**A shows that while producer **4** is an independent producer (and thus, a source producer), producer **5** is not. As a result, based upon the dependency declaration of producer **5**, producer **6** and a currently unresolved dependency are discovered. FIG. **5**A also shows that the currently unresolved dependency may be to producer **7**A and/or producer **7**B.

FIG. **5**B is a block diagram illustrating the initial execution of the producer graph of FIG. **5**A and the resolution of the unresolved dependency according to one embodiment of the invention. FIG. **5**B illustrates the producer graph of FIG. **5**A with curved arrowed lines showing execution of the producers and provision of their outputs to dependent parent producers. In addition, FIG. **5**B shows that the unresolved dependency of producer **5** is resolved as a dependency on producer **7**A, and that producer **7**A is an independent producer. Note that producer **7**A may be executed by itself, or be executed in parallel with producer **6**, or be executed in parallel with producer **4**, be executed in parallel with producer **3**, or be executed in parallel with any combination of producers **3**, **4**, and **6**. Such parallel execution is allowed because producer **7**A is independent of producers **3**, **4**, and **6**.

FIG. **5**C is a block diagram illustrating the initial execution of the producer graph of FIG. **5**A and/or the reexecution of the producer graph of FIG. **5**B according to one embodiment of the invention. FIG. **5**C illustrates the producer graph of FIG. **5**A with curved arrowed lines showing execution of the producers and provision of their outputs to dependent parent producers. In addition, FIG. **5**C shows that the unresolved dependency of producer **5** is resolved as a dependency on producer **7**B and that producer **7**B is a dependent producer. As a result, based upon the dependency declaration of producer **7**B, producer **8** is discovered. Producer **8** is an independent producer (and thus, is a source producer). Assuming that FIG. **5**C represents the initial execution of the producer graph of FIG. **5**A, all of the curved arrowed lines in FIG. **5**C would be employed. However, assuming that FIG. **5**C represents the reexecution of the producer graph of FIG. **5**B, the reexecution results in the dynamic dependency being resolved differently (a switch from producer **5** being dependent on producer **7**A to producer **7**B). Further, if the reexecution is performed without incremental execution, then all of the curved arrowed lines in FIG. **5**C would be employed; however, if incremental execution was used, only the non-dashed curved arrowed lines would be employed (producer **8** to producer **7**B, producer **7**B to producer **5**, producer **5** to producer **2**, and producer **2** to producer **1**). It should also be understood that the dynamic change in dependency illustrated in FIG. **5**C is exemplary, and thus any number of different situations could arise (e.g., the dynamic change may never occur; producer **5** could have first been dependent on producer **7**B and then changed to producer **7**A; producer **5** could have first been dependent on producer **7**B and no dynamic change ever occurs; producer **5** could be found to be dependent on both producer **7**A and producer **7**B as illustrated in FIG. **5**D; etc.) While different embodiments may resolve dynamic producer dependencies in different ways, some examples are provided later herein.

Thus, automated reexecution of a producer graph is not limited to the producer being modified and its direct parent being reexecuted; rather a change is automatically rippled

through the producer graph by the runtime, affecting any appropriate producers and dependencies, because the producer graphs are maintained (and incremental execution is used where supported). As such, changes cause any necessary additional discovery, building, resolving, and executing. Thus, the reexecution of a producer graph is automated in the sense that a user/programmer need not determine which producers of the producer graph are affected and possibly manually correct the graph.

Static Producer Dependencies

A static dependency is one that cannot change during run time. Thus, in an embodiment that supports contingent and subscription dynamic dependencies, a non-contingent, non-subscription dependency is a static dependency. The exemplary producer graph of FIG. **4**A illustrates a producer graph of static dependencies.

Producer Graph Shapes

Since a producer in object-oriented programming languages is at least a class, an instance of that class, and a method associated with that instance, a producer graph is class, instance and method centric. As such, a producer graph is a graph representing instances and methods associated with those instances, and thus, producer graphs are at least instance and method centric. In embodiments of the invention in which a producer is at least a class, a method, and an instance, producer graphs are at least class, method, and instance centric.

It should be understood that a producer graph may take a variety of different shapes (e.g., a single chain of producers, a tree, etc.). The exemplary producer graph of FIG. **5**B is a tree with a root node of producer **1**, from which there are two branches—one to each of producer **2** and producer **3**. Where producer **3** is a leaf node, producer **2** has two branches extending from it—one to each of producer **4** and producer **5**. Producer **5** has two branches extending from it—one to each of producer **6** and producer **7**A. The exemplary producer graph of FIG. **5**B is said to be multilevel, with level **1** including the root node producer **1**, with level **2** including producer **2** and producer **3**, with level **3** including producer **4** and producer **5**, with level **4** including producer **6** and producer **7**A (in FIG. **5**C, level **4** includes producer **7**B, and level **5** includes producer **8**). In some embodiments, parallelization may be implemented by executing producers on each level in parallel. Execution of producers may begin with the producers in the lowest level, such as level **5** in FIG. **5**C, and then moves up level-by-level. Before start executing producers on a level, the runtime may wait until all producers on a previous lower level are ready, i.e., the outputs of the producers on the previous lower level have been returned. When considering the branch from producer **1** with producer **2**, the first producer of the branch is producer **2** and the last producers of the branch are producer **4**, producer **6**, and producer **7**A in FIG. **5**B.

While FIG. **5**B illustrates a producer graph in which the current set of producers of interest includes a single producer, embodiments of the invention that support more than one current producer of interest would discover and build producer graphs for each. It should be understood that where there are simultaneously multiple producers of interest, the resulting producer graphs may be independent or may intersect. Where producer graphs intersect, embodiments of the invention may be implemented to: 1) duplicate producers to maintain separate producer graphs; or 2) avoid such duplication and maintain intersecting producer graphs. It should also be understood that such intersecting producer graphs may include a producer graph that is a subset of another producer graph. For instance, if producer **5** was included with producer **1** in the current set of producers of interest, then there would be a first producer graph with a root node of producer **5** and a second producer graph with a root node of producer **1**, where the second producer graph includes the first producer graph. If, for instance, producer **7**B was included with producer **1** and producer **5** in the current set of producers of interest, there would be a third producer graph, separate from the first and second producer graph, with a root node of producer **7**B in FIG. **5**B. Further, if the dynamic dependency of producer **5** changed from producer **7**A to producer **7**B (FIG. **5**C), then the change would result in the second producer graph and the third producer graph remaining (but not the first), with the third producer graph becoming a subset of the second producer graph remaining, and the second producer graph becoming a subset of the first producer graph. As previously stated, while embodiments of the invention may store and manipulate the producer graph(s) as a collection of producers that are linked to each other to form graph(s) (as opposed to a collection of graphs) to facilitate merging and splitting of producer graph(s). By way of example and not limitation, embodiments of the invention which store and manipulate the producer graph(s) as a collection of producers are described herein.

Exemplary Execution Flow

FIG. **6** is a flow diagram of a logical execution flow of a runtime client and its relationship to a runtime with producer graph oriented programming support according to one embodiment of the invention. In FIG. **6**, dashed dividing line **600** separates the logical execution flow of a runtime client **610** from the runtime with producer graph oriented programming support **640**.

The logical execution flow of the runtime client **610** includes blocks **615**, **620**, **625**, and **630**, while the runtime with producer graph oriented support **640** includes blocks **645**, **650**, **660**, and optionally **655**. A solid arrowed line represents a direct causal relationship from block **630** to block **660**. In contrast, dotted arrowed lines illustrate a causal relationship from blocks **615** and **625** in the logical execution flow of the runtime client **610** to blocks **645** and **650** in the runtime with producer graph oriented support **640**, respectively; depending on the embodiment of the invention, this causal relationship may be direct or indirect. For example, FIG. **6** illustrates an optional indirect causation through the use of a command log **665** in a dashed oval on the runtime with producer graph oriented support **640** side of the dashed line **600**. The command log **665** collects commands resulting from blocks **615** and **625** of the logical execution flow of the runtime client **610**; and the command log **655** is consumed, responsive to block **630**, by processing block **660**. Thus, the command log **665** allows for the delaying of commands in order to collect multiple ones together and batch process them for optimization purposes. Thus, the command log **665** is similar to the override log **396** of FIG. **3**B, and would actually include the override log **396** in some embodiments of the invention.

In block **615**, the set of one or more producers of interest are determined as the current set of producers of interest and control passes to block **620**. Responsive to the causal relationship between block **615** and block **645**, block **645** shows that the current set of producers of interest are instantiated and that an attempt is made to discover, build, and resolve (if dynamic dependencies are supported and one or more are discovered in the producer graph) the producer graph(s) for each, including instantiating any instances and producers thereof as necessary, based on the producer dependency declarations in the runtime client **610**. With reference to FIGS. **3**A and **3**B, the automated producer graph generation module **340** and **365** are invoked, respectively.

In block **620**, it is determined if there are any producer output overrides. If so, control passes to block **625**; otherwise, control passes to block **630**.

In block **625**, one or more producer output overrides are received for a set of one or more producers and control passes to block **630**. Responsive to the causal relationship between block **625** and block **650**, block **650** shows that the current set of overridden producers are instantiated (if not already instantiated in block **645**), their outputs are modified, and they are tracked. An overridden producer may have already been instantiated because it was already discovered to be part of the producer graph(s) in block **645**. However, an overridden producer may not already be discovered in block **645** because of an unresolved dynamic dependency. As such, this overridden producer is instantiated and overridden with the expectation that it may be added to the producer graph(s) when dynamic dependencies are resolved. Also, as previously indicated, the override log **396** of FIG. **3**B, if implemented, exists between block **625** and block **650** and is part of the command log **665**. Further, the set of overridden producers is tracked in some embodiments of the invention that support incremental execution. While in embodiments of the invention that support the override log **396**/command log **665** the tracking is part of the log, in alternative embodiments of the invention the tracking is separately performed in block **650** with a different mechanism.

In block **630**, the producer graph execution module is invoked and control optionally returns to block **615** and/or block **625**. Responsive to the causal relationship between block **630** and block **660**, block **660** shows that the current producer graph(s) are walked and any producers that require execution are executed based on the tracking. Various techniques have been previously discussed for executing the producers of the producer graph and are applicable here. With reference to FIGS. **3**A and **3**B, the producer graph execution module **345** and **370** are invoked, respectively. In addition, in embodiments of the invention in which the command log **665** is implemented, the causal relationship includes consuming the command log **665** and performing the processing blocks **645** and **650** prior to block **660**. Further, in embodiments of the invention that support the possibility of unresolved dependencies, control flows from block **660** to block **655** when necessary.

In block **655**, an attempt is made to resolve the unresolved dependencies and discover and build the remainder of the producer graph(s), including instantiating any instances and producers thereof. From block **655**, control flows back to block **660**.

Exemplary Forms of Producer Dependency Declarations

FIGS. **7**A-F illustrates some exemplary forms for producer dependency declarations according to embodiments of the invention. While FIGS. **7**A-F illustrate embodiments that support argument, field, and sequencing dependencies, it should be understood that different embodiments may support only one or two of the three dependency forms. In the embodiments of the invention shown in FIGS. **7**A-F, a producer dependency declaration is made up of a producer dependency declaration statement, and optionally explicit producer dependency declaration code. A non-shortcut declared producer dependency is one in which explicit producer dependency declaration code is used, whereas a shortcut declared producer dependency is one in which no explicit producer dependency declaration code is used (rather, the runtime does not use producer dependency declaration code and/or implements it on the fly based on information in the producer dependency declaration statement).

Different embodiments of the invention may use different syntaxes for declaring producer dependencies. For example, different embodiments of the invention may include different syntaxes for use in producer dependency declaration statements that strongly constrain, weakly constrain, and/or do not constrain the type of producer dependency that may be created. A strongly constrained producer dependency is one for which a syntax is used in the producer dependency declaration statement that substantially limits the type of producer dependency that may be created; A weakly constrained producer dependency is one for which a syntax is used in the producer dependency declaration statement that is less limiting of the type of producer dependency that may be created; and an unconstrained producer dependency is one for which a syntax is used in the producer dependency declaration statement that does not limit the type of producer dependency that may be created.

By way of example, and not limitation, embodiments of the invention described below that include the following: 1) a syntax for a strongly constrained producer dependency for arguments (ArgumentDependency=strongly constrained downwardly declared argument [static or dynamic, and if dynamic, contingent and/or absorbing subscription] dependency); 2) a syntax for a strongly constrained producer dependency for fields (FieldDependency=Strongly constrained downwardly declared field [static or dynamic, and if dynamic, contingent and/or absorbing subscription] dependency); 3) a syntax for a strongly constrained producer dependency for sequencing dependencies (SequencingDependency=Strongly constrained downwardly declared sequencing [static or dynamic, and if dynamic, contingent and/or sticky subscription] dependency); 4) a syntax for a weakly constrained upwardly declared producer dependency for argument, field, or sequencing dependencies (UpwardDependency=Weakly constrained upwardly declared field, argument, or sequencing [static or dynamic, and if dynamic, contingent] dependency); and 5) a syntax for a weakly constrained producer dependency (WeaklyConstrainedDependency=either a) downwardly declared sequencing only [static or dynamic, and if dynamic, contingent and/or sticky subscription] dependency; or b) upwardly declared [argument, field, or sequencing] [static or dynamic, and if dynamic, contingent] dependency). It should be understood that while some embodiments of the invention support a syntax for the producer dependency declaration statement that distinguishes downwardly declared argument dependencies, downwardly declared field dependencies, upwardly declared dependencies (that can return upwardly declared argument, field, or sequencing dependencies), and weakly constrained dependencies (that can return downwardly declared sequencing dependencies, upwardly declared argument, field, or sequencing dependencies), alternative embodiments of the invention may adopt a different syntax (e.g., have a syntax that has all dependencies be unconstrained dependencies with dependency determination producers that can return any supported dependencies (downwardly and upwardly declared argument, field, and sequencing dependencies); have a syntax distinguish all supported dependencies; have a syntax that distinguishes downwardly and upwardly declared argument and field dependencies and that distinguishes a weakly constrained dependency that can only return upwardly and downwardly declared sequencing dependencies; a syntax that distinguishes downwardly declared argument and field dependencies and that distinguishes upwardly declared dependencies that can return only upwardly declared sequencing dependencies; a syntax that distinguishes downwardly declared argument, field, and

sequencing dependencies (sticky subscriptions and upwardly declared dependencies are not supported); etc).

It should be understood that the syntax of the producer dependency declaration statement does not necessarily equate to the producer dependency (e.g., the link) created in the producer graph (e.g., ArgumentDependency creates an argument dependency; but an UpwardDependency may create an argument, field, or sequencing dependency). As such, where appropriate for understanding, a space between a qualifier (e.g., argument, field, or sequencing) and the word "dependency" is used to refer to the dependency created by the runtime, while lack of a space is used to refer to the syntax.

FIG. **7**A illustrates pseudo code of a producer dependency declaration for a method using shortcut declared dependencies according to one embodiment of the invention; while FIG. **7**B is a block diagram of exemplary producers according to one embodiment of the invention. FIG. **7**A shows: 1) a producer dependency declaration statement **705** including ArgumentDependencies **1**-N, FieldDependencies **1**-M, SequencingDependencies **1**-L, UpwardDependencies **1**-P, and WeaklyConstrainedDependencies **1**-Q; and 2) a method alpha **710** having arguments **1**-N from the producer dependency declaration statement **705**. In one embodiment of the invention, the arguments of a producer dependency declaration statement are numbered to provide an argument ID for each for tracking purposes. FIG. **7**B shows a producer **720** having child dependencies to the following: 1) producer **725** for argument ID **1**; 2) producer **730** for argument ID N; 3) producers **740**-**745** for field dependencies **1**-M; 4) producers **746**-**747** for SequencingDependencies **1**-L; and 5) producer **748**-**749** for UpwardDependencies **1**-P (note, WeaklyConstrainedDependencies **1**.Q are not shown, but will be described in greater detail with reference to FIG. **7**G). Thus, the arguments of the producer dependency declaration statement **705** correspond to the arguments of the method alpha **710**, and the argument IDs of the arguments in the producer dependency declaration statement **705** are tracked with regard to the child producers they identify.

FIG. **7**C illustrates pseudo code of a producer dependency declaration for a method using a non-shortcut declared dependency, and illustrates a block diagram of exemplary producers according to one embodiment of the invention. FIG. **7**C shows the producer dependency declaration statement **705** and the method alpha **710** of FIG. **7**A, as well as the producers **720** and **725** from FIG. **7**B. In addition, FIG. **7**C includes producer dependency declaration code **715** associated with Argument Dependency **1**. During run time, the runtime accesses and executes the producer dependency declaration code **715** responsive to Argument Dependency **1** of the producer dependency declaration statement **705**. Execution of the producer dependency declaration code **715** returns the producer **725** as the producer dependency for Argument Dependency **1**. Thus, FIG. **7**C illustrates embodiments of the invention in which producer dependency declaration code **715** may be part of a method (other than method alpha **710**), but is not part of a producer.

FIG. **7**D illustrates pseudo code of a producer dependency declaration for a method using a non-shortcut declared dependency according to one embodiment of the invention; while FIG. **7**E is a block diagram of exemplary producers according to one embodiment of the invention. FIG. **7**D shows the producer dependency declaration statement **705** and the method alpha **710** of FIG. **7**A, while FIG. **7**E shows the producers **720** and **725** from FIG. **7**B. In addition, FIG. **7**D includes: 1) a producer dependency declaration statement **750**; and 2) a method beta **755** including producer dependency declaration code **760**. FIG. **7**D also shows that argument dependency **1** of the producer dependency declaration statement **705** identifies a producer (shown in FIG. **7**E as producer **765**) based on the method beta **755** that will return the dependency for argument dependency **1**. During run time, the runtime, responsive to argument dependency **1** of the producer dependency declaration statement **705**, executes the producer **765** to return identification that the producer dependency for argument dependency **1** is producer **725**. As such, producer **765** is referred to as a dependency determination producer (its output is producer dependency—and thus, is returned using a class/instance that is monitored for special treatment (manipulation of the producer graph(s)) by the runtime with producer graph oriented programming support), whereas producer **725** is referred to as a standard producer (its output, if any, is not directly processed by the runtime to manipulate a producer graph; but its output, if any, may be consumed by a parent producer (be it a dependency determination producer or another standard producer) and/or provided as the output of the producer graph (if the standard producer is a producer of interest, and thus a root node).

Thus, FIGS. **7**D-E illustrate embodiments of the invention in which producer dependency declaration code **715** is part of another producer—referred to as a dependency determination producer. While in FIGS. **7**D-E the object-oriented source code includes explicit producer dependency declaration code in methods from which dependency determination producers are instantiated at run time by the runtime for non-shortcut declared dependencies, alternative embodiments of the invention additionally or instead implement the runtime to include generic producer dependency declaration code that it invokes as one or more generic dependency determination producers on the fly for shortcut declared dependencies. Also, while FIGS. **7**C-E are illustrated with reference to ArgumentDependencies, the techniques illustrated are applicable to the other types of downwardly declared dependencies. Further, FIGS. **7**F-G illustrate the use of a dependency determination producer for an UpwardDependency and a WeaklyConstrainedDependency.

FIG. **7**F is a block diagram of an exemplary dependency through use of an UpwardDependency with a dependency determination producer according to one embodiment of the invention. FIG. **7**F shows the producer **720** having sequencing producer dependency to a dependency determination producer **772**. The dependency determination producer may return a non-subscription upwardly declared argument, field, or sequencing dependency of the parent producer **748** on the producer **720**. Further, such a dependency determination producer may implement a dynamic dependency (e.g., a contingent dependency that selects between the above depending on data values, including between different argument IDs, as described later herein). While some embodiments of the invention support all of these possibilities, alternative embodiments of the invention support only a subset (e.g., only non-subscription upwardly declared sequencing dependencies).

FIG. **7**G is a block diagram of possible exemplary dependencies through use of a WeaklyConstrainedDependency with a dependency determination producer according to one embodiment of the invention. FIG. **7**G shows the producer **720** having sequencing producer dependency to a dependency determination producer **775**. In some embodiments of the invention, the dependency determination producer may return any of the following: 1) a non-subscription downwardly declared sequencing dependency on a child producer **780**; 2) a non-subscription upwardly declared argument, field, or sequencing dependency of a parent producer **785** on the producer **720**; and 3) a sticky subscription (described later

herein). Further, such a dependency determination producer may implement a dynamic dependency (e.g., a contingent dependency that selects between the above depending on data values, including between different argument IDs, as described later herein). While some embodiments of the invention support all of these possibilities, alternative embodiments of the invention support only a subset (e.g., only non-subscription upwardly declared sequencing dependencies).

As previously indicated, sequencing dependencies may be used for a variety of purposes, including ensuring the order of execution between producers that modify data in a manner of which the runtime is not aware and producers that consume that data (a child producer may write its outputs in a way that requires the method of the parent producer to include code to access that output (e.g., a method that impacts the environment by affecting an output that is not the regular producer output and, as such, that is not detected by the runtime—such as a method that sets a global variable, that sets a field in an instance which is not the producer output, that impacts an external data source, etc.)), etc. Affecting sources (such as global variables or external data sources) that the runtime is not aware of and reading from these sources is a feature that should be avoided in producers where parallelization capabilities are required.

Different embodiments may support one or more ways for declaring producer dependencies with respect to property producers. Specifically, in some embodiments of the invention, producers that read a field should be dependent on the get property producer, while the get property producer should be dependent on any producers that set the field for which that get property method is responsible. One technique of handling this situation that may be used in embodiments of the invention that support sequencing producer dependencies is to provide, for a get property method, a producer dependency declaration statement that creates sequencing producer dependencies on every method that sets the field for which that get property method is responsible (e.g., with respect to FIG. **7**G, where the producer **780** is a producer that sets a field and the producer **720** is the get property producer responsible for that field, the dependency determination producer **775** would be written to return a downwardly declared sequencing dependency of the producer **720** on the producer **780**). A second technique of handling this situation that may be used in embodiments of the invention that support both sequencing producer dependencies and upwardly declared producer dependencies is to include, in the producer dependency declaration statement/code for any method that sets a field, an upwardly declared sequencing producer dependency (e.g., using an UpwardDependency or WeaklyConstrainedDependency) on the get method responsible for that field (e.g., with respect to FIG. **7**G, where the producer **720** is a producer that sets a field and the producer **785** is the get property producer responsible for that field, the dependency determination producer **775** would written to return an upwardly declared sequencing dependency of the parent producer **785** on the producer **720**). This second technique allows the programmer of the method that sets the field to be responsible for providing a producer dependency to the appropriate get method, as opposed to requiring that programmer to go to the get method and modify its producer dependency declaration statement/code.

When using sequencing dependencies, when a given producer relies on a given variable, that variable should not be modified by more than one of that producer's descendant producers in a given execution of the producer graph(s) (It should be noted that through contingent dependencies (described later herein), different descendant producers may modify that variable during different executions of the current producer graph(s)). For example, a get property producer should only depend on one other producer that sets the filed for which the get property producer is responsible in a given execution of the current producer graph(s).

It should be understood that different embodiments of the invention may implement one or more of the embodiments of the invention shown in FIGS. **7**A-F. For example, one embodiment of the invention supports shortcut and non-shortcut declared dependencies, both using dependency determination producers; specifically, in this embodiment of the invention: 1) the object-oriented source code includes explicit producer dependency declaration code in methods from which dependency determination producers are instantiated at run time by the runtime for non-shortcut declared dependencies; 2) the runtime includes generic producer dependency declaration code that it invokes as one or more generic dependency determination producers on the fly for shortcut declared, contingent dependencies (describer later herein); and 3) the runtime includes support to directly link shortcut declared, non-contingent producer dependencies (describer later herein).

As another example, one embodiment of the invention supports non-shortcut and shortcut producer dependencies using dependency determination producers; specifically, in this embodiment of the invention: 1) the object-oriented source code includes explicit producer dependency declaration code in methods from which dependency determination producer are instantiated at run time by the runtime for non-shortcut declared dependencies; and 2) the runtime includes generic dependency determination code that it invokes as one or more generic dependency determination producers on the fly for shortcut declared dependencies (regardless of type). This later embodiment allows for consistent treatment of producer dependencies, and thus, simplifies the runtime.

In addition, while in one embodiment of the invention the producer dependency declaration statement for a method is located just above that method in the object-oriented source code, in alternative embodiments of the invention it is located elsewhere (e.g., the producer dependency declaration statements for all the methods for a class are grouped together within the class, the producer dependency declaration statements for all the methods in all of the classes are grouped together as a separate data table, etc.). Also, while in one embodiment of the invention producer dependency declaration code is separate from the producer dependency declaration statements, in alternative embodiments of the invention they are combined (e.g., the producer dependency declaration code is within the parentheses of the producer dependency declaration statement, the producer dependency declaration code is placed directly beneath the producer dependency declaration statement and is treated by the runtime as a single unit, etc.).

FIGS. **7**H-I illustrate the distinction between different subgraphs that may exist in a producer graph due to dependency determination producers. FIG. **7**H illustrates exemplary producer graphs of standard producers according to one embodiment of the invention. Specifically, FIG. **7**H shows a producer graph with root node **51**, a producer graph with root node S**5**, and a producer graph with root node S**11**. The standard producer **51** has as children standard producers S**2**, S**3**, and S**4**; standard producers S**2** and S**3** have as children standard producers S**7** and S**8**; standard producer S**5** has as children standard producers S**4** and S**6**; and standard producer S**11** has as children standard producers S**6** and S**10**. The exemplary producer graphs of FIG. **7**H may be discovered, built, and

revolved using any number of producer dependencies and dependency determination producers. FIG. **7**I illustrates one example of producer dependencies and dependency determination producers for discovering, resolving, and building the producer graph of FIG. **7**H. Specifically, FIG. **7**I shows the graphs of FIG. **7**H being subgraphs of a larger set of producer graphs. In other words, the producer graphs of FIG. **7**I include the graphs of FIG. **7**H (referred to as the "target subgraphs" and illustrated using solid arrowed lines and solid ovals) and graphs that assist in the discover, resolution, and building of the target subgraphs (referred to as "decision subgraphs and illustrated used dashed arrowed lines and dashed ovals). The decision subgraphs in FIG. **7**H include dependency determination producers (DDPs) **1**-**11** and standard producers S**9**-**10**. In FIG. **7**H, S**1** is shown as being dependent on DDPs **1**-**3**, which respectively return downwardly declared producer dependencies of S**1** on S**2**, S**3**, and S**4**; S**4** is shown as being dependent on DDP**4**, which returns an upwardly declared producer dependency of S**5** on S**4**; S**5** is shown as being dependent on DDP**5**, which returns a downwardly declared producer dependency of S**5** on S**6**; S**3** is shown as being dependent on DDP**6**, which in turn is dependent on DDP**8**, which returns a downwardly declared producer dependency of DDP**6** on S**9** and S**10**, which causes DDP**6** to return a downwardly declared dependency of S**3** on S**7**; S**3** is shown as being dependent on DDP**7**, which returns a downwardly declared producer dependency of S**3** on S**8**; S**8** is shown as being dependent on DDP**9**, which returns a sticky subscription for which S**6** is a trigger producer and S**11** is the created parent (thus, the producer dependency of S**11** on S**6**); S**2** is shown as being dependent on DDP**10**, which returns a collection of downwardly declared producer dependency of S**2** on S**7** and S**8**; and S**11** is shown as being dependent on DDP**11**, which returns a downwardly declared producer dependency of S**11** on S**10**. It should be understood that a standard producer may be both part of a target subgraph and a decision subgraph (e.g., see S**10**). It is worth noting that the target subgraphs are data driven in the sense that data flows from one standard producer to another standard producer up the graph.

Exemplary Programming and Execution Framework

FIG. **8**A is a block diagram illustrating a first exemplary framework within which applications are provided to end users according to one embodiment of the invention. The framework shown in FIG. **8**A includes three basic divisions. The first division includes the creation of the runtime with producer graph oriented programming support **810**. This first division is performed by programmers with highly advanced programming skills. When working in this division, programmers are referred to as runtime programmers. When creating a runtime with producer graph oriented programming support, the runtime programmers include support for producer graphs, as well as support for executing the various types of commands used in transformation code, instantiation code, and data preparation code.

The second division includes the creation of object-oriented application source code **820** to be executed by the runtime. The object-oriented application source code **820** includes two basic divisions: 1) class definitions that include the business logic expressed in methods with producer dependency declarations **822** (this may optionally include other functionality, such as a graphical user interface—in which case, the graphical user interface is written using producers and producer dependency declarations); and 2) class definitions that include client code expressed in methods **824**, including instantiation code (class, instances, and producer(s) of interest, to cause generation of the producer graph(s)) **824**A, data preparation code **824**B (e.g., set commands, such as set commands that trigger the overriding of producer outputs), global execute commands **824**C to cause execution of the producer graph(s) (e.g., execute and get commands), and any required graphical user interface **824**D (not included in **822**). The producer dependency declarations are used to define the ties between producers during the definition of the classes that include the business logic, rather than after instances of those classes are created. The object-oriented source code **820** is hard coded class, instance, and methods that are compiled and executed.

While in one embodiment of the invention a global execute command is implemented, execution of which causes the attempted execution of all producer graph(s) currently in the producer graph(s) structure **380**, alternative embodiments of the invention alternatively or also implement a graph specific execute command that requires identification of a given graph of the current producer graph(s) that is to be executed. Further, the global execute command may be explicit (e.g., set, set, set, execute, get, get) or implicit depending on the implementation of the runtime. For example, an implicit global execute command could be: 1) triggered by the first get command on a producer of interest (e.g., set, set, set, get (implicit execute), get); 2) trigger by each data manipulation (set (implicit execute), set (implicit execute), set (implicit execute), get, get); etc.

The second division is again performed by programmers with advanced programming skills, as well as an understanding of the business objectives of the application. When working in this division, programmers are referred to as application programmers. As part of this, if the application requires a graphical user interface, the application programmers also design and code the graphical user interface for the specific application; and thus are also referred to as application designers.

The third division includes the use of application programs being run by the runtime. The third division is performed by end users that need not have any programming skills. The application program may be distributed in a variety of ways (e.g., as source code; a transformation of source code, such as byte code; as binary, etc.). In addition, the application program may be distributed for stand alone use **830** (in which case, the entire application program (and runtime if not already present) is provided to a computer system) and/or client/server use. In one embodiment of the invention, a client/server distribution includes distributing the class definitions that include the business logic expressed in methods with producer dependency declarations **822** (and runtime if not already present) for server use **832** and the class definitions that include client code expressed in methods **824** (and runtime if not already present) for client use **834**, where the client use **834** on a computer system causes communication with the server use **832** on a server system.

FIG. **8**A also shows an optional configurable interactive producer output layout graphical user interface module **840** being provided for the standalone use **830** and the client use **834**. The object-oriented source code **820** would be run by the runtime to generate the producer graph(s), and the configurable interactive producer output layout graphical user interface module **840** allows for graphically displaying outputs from and interacting with the producer graphs. Specifically, the configurable interactive producer output layout graphical user interface module **840** includes: 1) a configuration and mapping graphical user interface module **844** to allow for the configuration of the layout and mapping of selected producer outputs (e.g., areas of the screen to be used, how the data is to be displayed, etc.); and 2) a rendering and interaction graphi-

cal user interface module **846** to render the configured layout and to allow for the overriding of producer outputs (which results in the updating of the producer graphs through a global execute command). It should be understood that the configurable interactive producer output layout graphical user interface module **840** may or may not be created by the same entity that writes the runtime **810**.

FIG. **8**B is a block diagram illustrating a second exemplary framework within which applications are provided to end users according to one embodiment of the invention. FIG. **8**B is identical to FIG. **8**A, with the following exceptions: 1) the stand alone used **830** is not present; 2) the object oriented source code **820** is provided to server use **832**, while the client code **824** is not provided to client use **834**; 3) the configurable interactive producer output layout graphical user interface module **840** is provided to server use **832** and not client use **834**; and 4) a generic configurable interactive producer output layout client interface **885** is provided to client use **834**. The configurable interactive producer output layout client interface **885** is used to interface with the configurable interactive producer output layout graphical user interface module **840**.

Regardless of the framework used, in one embodiment of the invention the producer graph oriented programming framework offers the ability to interface with programs not written with producer dependency declarations. This ability to interface with programs not written with producer dependency declarations includes: 1) a caller part (such as a graphical user interface not written according to producer graph oriented programming); and 2) a called part (such as an external data source not written according to producer graph oriented programming). The caller part may, through client code, issues producer graph oriented programming commands. The called part is implemented as part of producers that wrap the called part (referred to as "wrapping producers"). Executing the called part (such as reading data from a data source or subscribing to changes of data in an external data source) may in turn trigger instance modifications. These changes may occur by calling the property set methods in the code of the wrapping producers. Get property producers (getters) are caused to have dependencies on these wrapping producers, in order to make sure that instance modifications triggered by the changes occurring in an external data source are properly propagated through the producer graph. As previously described, different embodiments may support one or more ways for declaring producer dependencies with respect to property producers. For example, in some embodiments of the invention that support sequencing producer dependencies, SequencingDependencies may be used for declaring non-subscription downwardly declared sequencing producer dependencies on the wrapping producers. As yet another example, in some embodiments of the invention that support sequencing producer dependencies and non-subscription upwardly declared producer dependencies, UpwardDependencies and/or WeaklyConstrainedDependencies may be may be placed in the producer dependency declaration of the wrapping producers to create non-subscription upwardly declared sequencing producer dependencies for the property producers.

FIGS. **8**C-F illustrate exemplary screenshots and usage of the configurable interactive producer output layout graphical user interface module **840** according to one embodiment of the invention. While embodiments of the invention will be described with reference to the configurable interactive producer output layout graphical user interface module **840** providing for the configuration, mapping, and interaction with selected outputs of the current producers graph(s) in the form of a spreadsheet, alternative embodiments of the invention may be implemented to additionally or alternatively provide support for another form. Further, while exemplary ways of performing the configuration, mapping, and interaction in the form of a spreadsheet is described according to some embodiments, other embodiments of the invention may perform these operations another way, with different interface, and/or with a different screen layout. Further, the spreadsheet may support any of the known functionalities associated with spreadsheets (e.g., color selection, font selection, bar/pie/line charts, pivot tables, saving layouts, loading layouts, etc.).

FIGS. **8**C-D illustrate exemplary screenshots and usage of free cell selection according to one embodiment of the invention, while FIGS. **8**E-F illustrate exemplary screenshots and usage of table creation according to one embodiment of the invention. Each of FIGS. **8**C-F include a menu bar **850** along the top of the screen, a list of classes (with their get property methods) **852** of the producers in the current producer graph and their outputs down the left side of the screen, and a configuration and mapping viewer **854** filling the remainder of the screen with a spreadsheet like layout. In addition, FIGS. **8**C-F also show the following exemplary list of classes with their get property methods in the list **852**: 1) the class PERSON; 2) the get property methods of the class person including FIRSTNAME (e.g., string), LASTNAME (e.g., string), GENDER (e.g., string), HOMEADDRESS (instance of the class ADDRESS), PROFESSIONALADDRESS (instance of the class ADDRESS), DATEOFBIRTH (e.g., date), and AGE (e.g., integer); 3) the class ADDRESS; and 4) the get property methods of the class ADDRESS including CITY (e.g., string), STATE (e.g., string), ZIPCODE (e.g., string). As such, the current producer graph includes producers of the classes PERSON and ADDRESS, as well as producers whose outputs are of classes PERSON and ADDRESS. It is also worth nothing that the get property method AGE calculates an age based on the output of the get property method DATEOFBIRTH; as such, a producer instantiated from the get property method AGE will be dependent on a producer instantiated from the get property method DATEOFBIRTH.

FIGS. **8**C-D show the following free text entered in consecutive cells of the first column of the viewer: CUSTOMER, FIRST NAME, LAST NAME, DATE OF BIRTH, and AGE; while FIGS. **8**E-F show the following: 1) free text entered in the first row of the viewer—CUSTOMER LIST; and 2) free text entered in consecutive cells of the second row of the viewer FIRST NAME, LAST NAME, DATE OF BIRTH, AND AGE.

FIG. **8**C illustrates an exemplary screenshot and usage of free cell selection with the configurable interactive producer output layout graphical user interface module **840** according to one embodiment of the invention. FIG. **8**C shows a set of mappings **856** of the class PERSON and selected get property methods of the class PERSON to different cells of the viewer. Specifically, the class PERSON is mapped to the cell to the right of the free text CUSTOMER. As part of this action, some embodiments of the invention prompt the user to select from one of a number of supported filters (show as filter selection **858**) (e.g., drop down list, form scrolling arrows, etc.). These filters enable the selection of one or more instance keys of producers of the selected class, or one or more instance keys of the producers whose output class is the selected class. While some embodiments of the invention support a number of filters, other embodiments of the invention default to one (and allow the user to chose whether to select a different one) or support only one and do not need to perform filter selection **858**. The mappings **856** also show that the get property methods FIRSTNAME, LASTNAME, DATEOFBIRTH, and AGE of the class PERSON are respectively mapped to the

cells adjacent to the cells with corresponding free text. Such a mapping may be performed with any number of well known techniques, including drag and drop, typing in a GUI field, etc.

FIG. **8**D illustrates another exemplary screenshot and usage of free cell selection with the configurable interactive producer output layout graphical user interface module **840** according to one embodiment of the invention. FIG. **8**D shows that the cell to which the class PERSON was mapped to allow for instance selection **854**. Specifically, based on the filter used for this cell, the user is given the opportunity to select an instance of the class PERSON from a list including the instance keys (s) of the producers of the class PERSON, and the instance keys of the producers producing the class PERSON. The selection of an instance of the class PERSON (or the existence of a single instance) results the automatic population of the cells, to which the get property methods of the class PERSON were mapped, with the outputs of the corresponding get property methods of that instance. This populating of the table based on the instances of the class PERSON is labeled **858**. In the example of FIG. **8**D, the cells to which the get property methods FIRSTNAME, LASTNAME, DATEOFBIRTH, and AGE of the class PERSON were mapped being respectively populated with JOHN, SMITH, Jul. 20, 1990, and 16.

FIG. **8**D also shows that cells of the viewer to which get property methods have been mapped may be overridden. By way of example, FIG. **8**D shows that if the cell to which the get property method DATEOFBIRTH is mapped is overridden, then it will cause the overriding of the output of the producer whose output is currently populating that cell, invocation of a global execute command (which would result in a reexecution of the producer whose output is currently populating the cell to which the get property method AGE is mapped), and any necessary updating of the display.

FIG. **8**E illustrates an exemplary screenshot and usage of table creation with the configurable interactive producer output layout graphical user interface module **840** according to one embodiment of the invention. FIG. **8**E shows a zone and orientation selection **864** operation is performed to identify a three row vertical table directly under the cells with free text FIRST NAME, LAST NAME, DATE OF BIRTH, AND AGE (illustrated with a thick dashed line around these cells). Different embodiments of the invention may support the user performing this operation any number of ways (including: 1) selection of an area with an input device like a mouse; and 2) selection between a vertical, horizontal, or pivot table with an interface like a popup menu—assuming multiple orientations are supported). FIG. **8**E also shows a set of mappings **866** of selected get property methods of the class PERSON to different cells of the viewer. Specifically, the mappings **866** show that the get property methods FIRSTNAME, LASTNAME, DATEOFBIRTH, and AGE of the class PERSON are respectively mapped to the cells directly beneath the cells with corresponding free text.

FIG. **8**F illustrates another exemplary screenshot and usage of table creation with the configurable interactive producer output layout graphical user interface module **840** according to one embodiment of the invention. The mappings **866** results in the automatic population of the columns of the table, to which the get property methods of the class PERSON were mapped, with the outputs of the corresponding get property methods of the instances of that class. This populating of the table based on the instances of the class PERSON is labeled **868**. In the example of FIG. **8**D, the columns to which the get property methods FIRSTNAME, LASTNAME, DATEOFBIRTH, and AGE of the class PERSON were mapped being populated with the following rows of data: 1) STEVE, COLLINS, Jul. 20, 1990, and 16; 2) JENNIFER, ADAMS, Jul. 20, 1990, and 16; and 3) JOHN, SMITH, Jul. 20, 1985, and 21.

As in FIG. **8**D, FIG. **8**F shows that cells of the viewer to which get property methods have been mapped may be overridden. By way of example, FIG. **8**F shows that if the cell of the second row of the column to which the get property method DATEOFBIRTH is mapped is overridden, then it will cause the overriding of the output of the producer whose output is currently populating that cell, invocation of a global execute command (which would result in a reexecution of the producer whose output is currently populating the cell to which the get property method AGE is mapped), and any necessary updating of the display.

FIGS. **8**C-F illustrate exemplary screens generated by the configuration and mapping graphical user interface module **842**. The screens generated by the rendering and interactive graphical user interface module **846** are the same, with the exception that the list of classes (with their get property methods) **852** the configuration and mapping viewer **854** are replaced by a rendering and interactive viewer (not shown) that contains the same image as the configuration and mapping viewer **854** displayed (the difference being the mapping feature is no longer available).

Exemplary Runtime Distribution Schemes

FIGS. **9**A-C illustrate various schemes for distributing a runtime with producer graph oriented programming support. It should be understood that these distribution schemes are exemplary, and thus other schemes are within the scope of the invention.

FIG. **9**A is a block diagram illustrating a first scheme for distributing a runtime with producer graph oriented programming support according to one embodiment of the invention. In FIG. **9**A, object-oriented source code **905** (which would include producer dependency declarations) is shown on top of a runtime with producer graph oriented programming support **910**, which is on top of a runtime with class loading, dynamic class instantiation, dynamic single method invocation, and class/method introspection **915**, which is on top of an operating system **920**. In FIG. **9**A, the runtime **910** works with the runtime **915**. While any number of mechanisms may be used to allow runtime **910** to work with runtime **915**, a metadata facility is described by way of example. A metadata facility allows additional information to be added to source code, which information is used by development tools. For example, the Metadata Facility for Java specification defines an API for annotating fields, methods, and classes as having particular attributes that indicate they should be processed in special ways by development tools, deployment tools, or run-time libraries (Java Specification Request 175). In this example, a programmer programming the object-oriented source code **905** would add annotations to methods in the form of the producer dependency declarations. Since these annotations are handed off by the runtime **915** to the runtime **910**, the runtime **910** dictates the syntax of the producer dependency declarations. In FIG. **9**A, the runtimes **910** and **915** may be developed and/or distributed by different organizations.

FIG. **9**B is a block diagram illustrating a second scheme for distributing a runtime with producer graph oriented programming support according to one embodiment of the invention. In FIG. **9**B, object-oriented source code **925** (which would include producer dependency declarations) is shown on top of a runtime (with class loading, dynamic class instantiation, dynamic single method invocation, and class/method introspection, as well as producer graph oriented programming

support) **930**, which is on top of an operating system **935**. In comparison to FIG. **9**A, the runtime **910** and **915** have been combined into a single runtime **930**. As a result of this combination, the runtime **930** dictates the syntax of the producer dependency declarations. Thus, a programmer programming the object-oriented source code **925** would add the producer dependency declarations in the required syntax.

FIG. **9**C is a block diagram illustrating a third scheme for distributing a runtime with producer graph oriented programming support according to one embodiment of the invention. In FIG. **9**C, object-oriented source code **940** (which would include producer dependency declarations) is shown on top of an operating system runtime (with class loading, dynamic class instantiation, dynamic single method invocation, and class/method introspection, as well as producer graph oriented programming support) **945**. In comparison to FIG. **9**B, the runtime **920** and operating system **935** have been combined into a single entity. As a result of this combination, the operating system runtime **945** dictates the syntax of the producer dependency declarations. Thus, a programmer programming the object-oriented source code **940** would add the producer dependency declarations in the required syntax.

While embodiments are described in which the runtime has class loading, dynamic class instantiation, dynamic single method invocation, and class/method introspection, alternative embodiments may include more or less features (e.g., instance cloning, dynamic proxies, primitive type conversions, etc.).

Exemplary Advantages

In one embodiment of the invention, producer dependencies are declared for methods as a way to specify method invocation sequencing using the appropriate instances (where the appropriate instances include the instances to use as arguments, the instances to be used by instance methods, and the meta class instances used by class methods) without using manual invocation sequencing code. Effectively, the work of generating some or all of manual invocation sequencing code is replaced with: 1) work done by the application programmer to write the producer dependency declarations; and 2) work done by the runtime to discover and build the producer graph(s) and execute the producers of those producer graph(s). In other words, the logic that was previously contained in the manual invocation sequencing code is discoverable by the runtime during run time based on the producer dependency declarations. Thus, the producer dependency declarations inform the runtime what methods of what instances with what arguments to execute, and when for synchronization purposes. Although the effort to write the runtime is relatively great, it needs only be written once in that it can be used to execute any object-oriented applications written for the runtime; in contrast, for a typical application, the effort to write the producer dependency declarations is relatively low in comparison to writing manual invocation sequencing code.

Reducing Programming Mistakes

Producer graph oriented programming typically reduces the costs associated with the debugging and/or performance tuning of the manual invocation sequencing code. This is true for at least the reason that the infrastructure of an application program is conceptually a set of non-formalized graphs of transformation methods of objects (the output of one method of an object is the input to another, and so on) that operate on specific inputs. The producer dependency declarations and the runtime with producer graph oriented programming support formalizes these graphs as producer graphs. Thus, for each opportunity for data to change, the application programmer need not consider its effect and write manual invocation sequencing code to cause the appropriate transformation methods of the appropriate instances to be invoked in the appropriate order with the appropriate inputs. In other words, for each opportunity for data to change, an application programmer need not consider which graphs are affected, as well as which transformation methods of instances within those graphs are affected. Rather, the automated producer graph generation module discovers and builds the producer graphs and the producer graph execution module reexecutes the producer graphs as needed to reflect changes in the data. This automation helps application programmers avoid mistakes such as: 1) invoking the appropriate transformation methods of the appropriate instances in the wrong order; 2) forgetting to include commands to cause the one or more required transformation methods of instances in a graph to be invoked responsive to some data being changed; 3) including commands to cause unnecessary transformation methods of instances to be invoked responsive to some data being changed (e.g., including commands to invoke transformation methods of instances that are not part of a graph affected by the change in data; including commands to invoke transformation methods of instances that are part of a graph affected by the change in the data, but are not themselves affected; etc.).

Synchronization

As previously described, the caching of producer outputs during execution allows for synchronization. Thus, in terms of comparison to the observer pattern, the producer dependency declarations notify a runtime with producer graph oriented programming support of the dependencies, and the runtime determines what producers and when to call back.

Ability to Fully Explain any Result

In one embodiment of the invention, a drilling/viewing module (not shown) is included as part of the runtime. The drilling/viewing module provides a graphical user interface which, through interaction by an end user, allows for drilling down into the producer graph (walking down a producer graph from the root node) to view the outputs of the various producers of the producer graph. This allows an end user to see the various outputs that contributed to the output of the producer of interest, including the data values and dependencies (returned by dependency determination producers). Further, in one embodiment of the invention, this drilling/viewing module provides the ability for the end user to view the code inside the methods of the producers, the values of the instances of the producers, and/or the content of the classes of the producers.

Thus, the drilling/viewing module provides for a variety of post processing activities, including debugging, explanation of outputs, etc.

Exemplary Practical Application/Technical Affect/Industrial Applicability

There are a variety of exemplary practical applications of the different aspects and embodiments of the invention. For example, the runtime, as part of executing application programs, causes the retrieval of information from a machine storage media (e.g., accessing the object-oriented source code, including the producer dependency declarations), the storage of information to a machine storage media (e.g., storing data structures like the producer graph(s) structure, etc.), the operation of hardware processing resources, the provision of the outputs of the producer(s) of interest (e.g., through a graphical user interface, storage to machine storage media, transmission, etc.), etc. In one sense, preprocessing activity includes the writing of such an application program and/or the provision of data (which data may represent any number of physical and/or practical items, such as financial values, geographical values, meteorological values, actuarial

values, statistical values, physical measures, machine state values, etc.), while post processing activity includes the provision of results (which results may represent any number of physical and or practical items, such as financial analysis, geographical analysis, meteorological analysis, actuarial analysis, statistical analysis, industrial measures, machine control information, etc.). By way of specific example, post processing activity may be provided by: 1) the producer graph viewer module **1062** of FIG. **10** for graphically displaying a representation of the current producer graph(s) generated by the runtime; and/or 2) the configurable interactive producer output layout graphical user interface module **840** (see also, configurable interactive producer output layout graphical user interface module **1085** of FIG. **10**) for graphically displaying outputs from and interacting with the producer graphs.

As another example, the application program with producer dependency declarations itself, when executed by the runtime, represents the physical/practical items and causes the operations described above. By way of specific example, these producer dependency declarations cause data structures to be formed in machine storage media responsive to their execution by the runtime. Also, the producer dependency declarations are stored and retrieved from machine storage media along with the application program. Further, these producer dependency declarations represent relationships between producers, while producers represent operations to be performed (methods) and instances. The instances in object-oriented programming may be used to represent physical and/or practical items, while the producers represent operations to be performed on these representations.

By way of another example, a set of one or more application programs and the runtime implement cross-asset risk management software covering foreign exchange, equity, interest rate, credit, inflation, commodity, and cross-asset composite products. These products range from cash and physical plain vanilla products to exotic and complex derivative products. Also included is a set of mathematical valuation models for these products, and their associated market data, payment and accounting entries generation routines and their associated observables, calibration models and their associated raw inputs.

By way of another example, a set of one or more application programs and the runtime may implement a word processor, a spreadsheet, a communication/e-mail software, a photo viewing software, a virus scan software, a media player, a database server, a game, an industrial application, and/or an operating system. Of course, application programs can be implemented to perform a variety of other tasks.

Exemplary Implementations

By way of illustration, exemplary embodiments of the invention will be described that support dependencies, dynamic dependencies (including contingent dependencies and subscription dependencies), explicit dependency determination producers for shortcut declared dependencies and for non-shortcut declared dependencies, on the fly dependency determination producers for shortcut declared dependencies, class keys, instance keys, method keys, producer override/unoverride commands (which are types of set commands), and global execute commands. In addition, the exemplary embodiments optionally support a producer graph interactive viewer module and incremental execution. Of course, alternative embodiments of the invention may implement more, less, and/or different features.

FIG. **10** is a block diagram of an exemplary implementation according to one embodiment of the invention. In FIG. **10**, dashed dividing line **1000** separates a runtime client **1002** from a runtime with producer graph oriented programming support **1004**.

The logical execution flow of the runtime client **1002** includes blocks **1010**, **1020**, **1025**, **1030**, and **1035**, and the runtime with producer graph oriented programming support **1004** includes respectively corresponding blocks **1095**, **1098**, **1040**, **1045**, **1070**, and **1082**; while a solid arrowed line represents a direct causal relationship from block **1035** of the logical execution flow of the runtime client **1002** to block **1070** of the runtime with producer graph oriented programming support **1004**, dotted arrowed lines illustrate a causal relationship from blocks **1010**, **1020**, **1025**, and **1030** of the runtime client **1002** to blocks **1095**, **1098**, **1040**, and **1045** of the runtime with producer graph oriented programming support **1004**. Depending on the embodiment of the invention, these later causal relationships may be direct or indirect. For example, similar to FIG. **6**, an optional indirect causation through the use of a command log (not shown) and/or override log **1047** may be used. Further blocks **1095** and **1098** are dashed because they may optionally be part of a different block depending on the embodiment of the invention (e.g., block **1095** may be part of block **1098**; block **1090** may be part of block **1040**; blocks **1095** and **1090** may be part of block **1040**). Similarly, block **1045** is dashed because it may be optionally part of a different block depending on the embodiment of the invention (e.g., block **1045** may be part of block **1070**). Likewise, block **1049** may be optionally part of a different block depending on the embodiment of the invention (e.g., block **1049** may be part of block **1040**). In some embodiments, the runtime **1004** includes a metrics acquisition module **1082**. The metrics acquisition module **1082** may optionally be part of block **1070**.

In FIG. **10**, the runtime **1002** includes class definitions that include business logic **1010** having data **1012**, methods **1014**, execution mode setting **1015**, producer dependency declarations **1016**, and optionally class keys **1090**. The class definitions **1010** are classes in an object-oriented programming language, and thus include definitions for data **1012** and methods **1014**. The execution mode setting **1015** may specify at code level an execution mode in which the method is to be executed if the execution mode setting is not overridden later. In addition, these class definitions **1010** include producer dependency declarations **1016** for the method **1014** as previously described. Further, in one embodiment of the invention, each class has a class key **1090** for tracking purposes.

The new class module **1095** of the runtime **1004** loads and introspects the class definitions **1010** (e.g., responsive to new class commands). This loading and introspecting may be done using any number of well known or future developed techniques, including those to selectively load classes for optimization purposes. The loading of the classes by the new class module **1095** is illustrated by classes **1054** of the runtime **1004**. As part of loading and introspecting the classes **1054**, the new class module **1095** also loads and introspects the producer dependency declarations **1016** as illustrated by methods and producer dependency declarations **1056** in the classes **1054**. The new class module **1095** also maintains a class tracking structure **1092** that is used for tracking the classes using the class keys. Thus, the class tracking structure **1092** maintains a correspondence between class keys and references into the classes **1054**. In addition, the new class module **1095** also maintains a method tracking structure **1058** that is used for tracking methods using the method keys. Thus, the method tracking structure **1058** maintains a correspondence between method keys and references to the methods, as well as information regarding the producer depen-

dency declarations. Further, the new class module **1095** may input the execution mode setting **1015** to the producer-based configurable decision structure **1049**, which maintains the execution modes for producers.

The runtime client **1002** also includes instance instantiation commands with instance keys **1020**. The new instance module **1098** of the runtime **1004** instantiates the instances designated by the instance instantiation commands with instance keys **1020** (e.g., responsive to new instance commands). This instantiation of instances may be done using any number of well known or future developed techniques, including those to selectively instantiate instances for optimization purposes. As part of this instantiation of instances, the new instance module **1098** accesses the class tracking structure **1092** using a class key to access the appropriate class from the classes **1054**. The instantiation of instances by the new instance module **1098** is illustrated by instances **1052** of the runtime **1004**. The new instance module **1095** also maintains an instance tracking structure **1065** that is used for tracking the instances using the instance keys. Thus, the instance tracking structure **1065** maintains a correspondence between instance keys and references into the instances **1052**. As previously indicated, the new class module **1095** may be part of the new instance module **1098** in that the classes **1054** may be instantiated responsive to the instance instantiation commands **1020**, as opposed to separate new class commands.

The runtime client **1002** also includes producer instantiation commands with producer keys **1025**. The automated producer graph generation module **1040** of the runtime **1004** loads producers designated by the producer instantiation commands with producer keys **1025** (e.g., responsive to new producer commands designating the current set of producers of interest). In addition, the automated producer graph generation module **1040** also discovers, builds, and optionally resolves the producer graph(s) responsive to the current set of producers of interest as previously described. In one embodiment of the invention, a producer key is comprised of a class key, instance key, and method key. As part of this instantiating of producers, the automated producer graph generation module **1040**: 1) accesses the class tracking structure **1092** using the class key to access the appropriate class from the classes **1054**; 2) accesses the instance tracking structure **1065** using the instance key to access the appropriate instance from the instances **1052**; and 3) accesses the method tracking structure **1058** using the method key to access the appropriate producer dependency declaration statement. The instantiating of the producers designated by the producer instantiation commands with producer keys **1025** and instantiating of the any discovered producers and building the producer graph is illustrated by producer graph(s) structure **1060** of the runtime **1004**. Thus, in one embodiment of the invention, the producer keys identified by the producer instantiation commands with producer keys **1025** and those discovered through producer graph generation are stored in the producer graph(s) structure **1060**, along with addition information to represent the current producer graph(s).

As previously described, the block **1095** and **1098** may be part of block **1040**, and thus, the decision regarding which classes, instances, and producers to load/instantiate is driven by what producers are in the current producer graph(s). In such an embodiment of the invention, the loading/instantiation of class, instances, and producers is optimized and is producer centric.

The runtime client **1002** also includes data preparation commands, including producer output override/unoverride commands **1030**. The override/unoverride commands include the producer key of the producer to be overridden/unoverriden, as well as the override values when being overridden. The override producer output module **1045** of the runtime **1004** causes producers designated by the producer override/unoverride commands to be overridden/unoverriden. This causation may be indirect or direct.

In the case of indirect causation, the override producer output module **1045** populates the override log **1047** for consumption by the producer graph execution module **1070**. In the case of direct causation, the override producer output module **1045** accesses the producer output caching **1097** of the producer graph(s) structure **1060** and the instances **1052**. Specifically, as described with reference to the override producer output module **390**, in one embodiment, producers can be classified as property producers or method producers; thus, the override producer output module **1045** may include an override property producer output module for overridden property producers and an override method producer output module for overridden method producers (not shown); the overriding of a property method causes the overridden value to be stored in the producer output caching **1097** of the producer graph(s) structure **1060** and to be stored in the data of the appropriate instance of the instances **1052**, whereas the overriding of a method producer causes the overridden value to be stored in the producer output caching **1097**.

In one embodiment of the invention producers may not be overridden before a producer graph of which they will be part has been initially executed (thus, the producer will already be instantiated as a result of being designated as a producer of interest or as a result of being discovered by the automated producer graph generation module **1040**). However, in the embodiment shown in FIG. **10**, producers may be overridden before the initial execution by being instantiated and overridden with a producer override command. Such an overridden producer will typically eventually become part of a producer graph through the discovery process (e.g., when a dynamic dependency is resolved). In some embodiments of the invention, this data preparation may also include other types of set commands. The override producer output module **1045** is shown as a dashed box because it may not be present in alternative embodiments of the invention.

The producer graph(s) structure **1060** also optionally includes incremental execution marking **1080** for some embodiments of the invention that support incremental execution. As previously described with reference to the incremental execution marking **382** of FIG. **3**B, the incremental execution markings **1080** is used to assist with incremental execution of the producer graph(s) on execution beyond that of the initial execution. Different embodiments of the invention that use the incremental execution marking **382**, use them in different ways. For example, in one such embodiment of the invention that has a command log, the log is used to track which producers have been added and/or modified, and the incremental execution marking **382** are used to mark those producers that are affected (ancestors of the modified or added producers, and thus dependent on them). As another example, in one such embodiment of the invention that does not have a command log, the incremental execution marking **382** are used to mark those producers that are added or modified, as well as those that are ancestors of the modified or added producers (and thus dependent on them). As another example, in one such embodiment of the invention that does not have a command log, modifications and additions of producers are done immediately and the incremental execution marking **382** are used to mark those producers that are ancestors of the modified or added producers (and thus dependent on them). While embodiments of the invention

have been described that support incremental execution and use incremental execution marking, other embodiments of the invention support incremental execution that do not use incremental execution marking (e.g., a command log is used to track which producers were added or modified, and a list of execution start producers is maintained in an execution start log; where the producer graph execution module **1070** starts from the execution start producers and works its way up the ancestors of the producer graph(s) to the top; by way of example and not limitation, this embodiment of the invention is described later herein with regard to FIGS. **15-25**.

The runtime client **1002** also includes execution mode selection commands **1036** according to some embodiments of the invention. A user may use the execution mode selection commands **1036** to change the execution mode setting(s) by changing the runtime setting structure **1048**, the producer-based configuration decision structure **1049**, and/or the producer graph structure **1060**. In one embodiment, the execution mode selection commands **1036** change the producer-based configuration decision structure **1049** to modify the execution mode settings of a particular class, a particular instance, a particular method, or any combination of the above. For example, a first execution mode selection command may change the execution mode setting of all methods of a particular class to a first execution mode, a second execution mode selection command may change the execution mode setting of a particular instance of a particular class, a third execution mode selection command may change the execution mode setting of a particular method, a fourth execution mode selection command may change the execution mode setting of a particular method and a particular instance, and so on. Alternatively, a user may use the execution mode selection commands **1036** to change the execution mode setting(s) on a producer-by-producer basis by changing the producer graph structure **1060**. Since each producer in the producer graph structure **1060** has a producer execution mode setting, the execution mode selection commands **1036** may provide a producer key identifying a particular producer and a desired execution mode setting for the particular producer to cause the runtime **1004** to change the execution mode setting for the particular producer to the desired execution mode setting.

The runtime client **1002** also includes global execution commands **1035**. The producer graph execution module **1070** of the runtime **1004** executes the producer graph(s). The producer execution module **1070** may execute each producer in the producer graph(s) based on the corresponding execution mode of the producer from the producer-based configuration structure **1049**. In some embodiments, the producer execution module **1070** may override the execution mode of a predetermined producer from the producer-based configuration structure **1049**. For instance, if the execution mode from the producer-based configuration structure **1049** is not supported by the runtime **1004**, then the producer execution module **1070** may override such execution mode.

In some embodiments, the runtime **1004** supports three execution modes namely, multiprocessing, multithreading, and local execution. Thus, the producer execution module **1070** includes a parallelization module **1076**, a multiprocessing module **1077**, a multithreading module **1078**, and a local execution module **1079**. For each producer, the automatic producer graph generation module **1040** may find the corresponding execution mode from the producer-based configuration decision structure **1049** and may set the producer execution mode setting accordingly in the producer graph structure **1060** if the corresponding execution mode is not overridden by a runtime setting in the runtime setting structure **1048**. Based on the producer execution mode setting in the producer graph structure **1060**, the parallelization module **1076** may send the producer to a corresponding one of the multiprocessing module **1077**, the multithreading module **1078**, and the local execution module **1079**. Then a task may be instantiated for the producer at the multiprocessing module **1077**, the multithreading module **1078**, and/or the local execution module **1079**. A task is a logically high level, discrete, independent section of computational work. A task is typically executed by a processor as a program.

In some embodiments, if the execution mode is multiprocessing, then the parallelization module **1076** may send the producer to the multiprocessing module **1077**. The multiprocessing module **1077** may serialize the task corresponding to the producer as well as the inputs to the producer, and add the serialized task and inputs to a job. When the tasks corresponding to all ready to be executed producers having an execution mode of multiprocessing have been added to the job, the multiprocessing module **1077** may send the job to a grid dispatcher **1081** to be forwarded to a grid of processors. Then some or all of the processors in the grid may execute the tasks in the job distantly. If the execution mode is multithreading, then the parallelization module **1076** may send the producer to the multithreading module **1078**. The multithreading module **1078** may initiate a thread pooling mechanism and feed the task corresponding to the producer to an available thread to be executed. If the execution mode is local execution, then the parallelization module **1076** may send the producer to the local module **1079**. The local module **1079** may then execute the task within the current runtime thread.

In some embodiments, the parallelization module **1076** may send a producer to a predetermined one of the multiprocessing module **1077**, the multithreading module **1078**, and the local execution module **1079** by default if no execution mode has been specified for the producer. On the other hand, if the class definition **1010** of the producer includes an execution mode setting **1015** for the producer, the parallelization module **1076** may send the producer according to the execution mode setting **1015** unless the execution mode setting **1015** is overridden. The execution mode setting **1015** may be overridden in various ways. In one embodiment, the execution mode selection commands **1036** changes the execution mode settings in the producer-based configurable decision structure **1049** on a class basis, a method basis, an instance basis, or any combination of the above, to override the execution mode setting **1015**. In one embodiment, the execution mode selection commands **1036** changes the execution mode settings on a producer-by-producer basis in the producer graph structure **1060** to override the execution mode setting determined using the producer-based configurable decision structure **1049**. In one embodiment, the execution mode selection commands **1036** changes the execution mode settings on a runtime global level in the runtime setting structure **1048** to override the execution mode settings in the producer graph structure **1060**.

As such, the producer graph execution module **1070** modifies the producer output caching **1097** (in the case of property producers and method producers), uses the incremental execution marking **1080** (if present), and modifies the data of the instances **1052** (in the case of property methods). In some embodiments, the metrics acquisition module **1082** may acquire metrics during execution of the producers. The metrics acquired may be stored in metrics **1083** in the producer graph(s) structure **1060**. Note that the metrics may be acquired on a producer basis, and since a producer includes a unique combination of a class, a method, and an instance, the

metrics acquired may be on a class-instance-method basis. Furthermore, the metrics acquired may be on a task basis and/or on a job basis.

In some embodiments, the metrics acquired include different types of metrics for different usages, such as for monitoring the computing environment, for monitoring distant execution time, for monitoring local execution time, for monitoring data streams, for monitoring overall execution time, for benchmarking different types of execution, etc. For example, to monitor the computing environment, metrics such as the number of processors or engines available on a remote grid used in multiprocessing and dedicated to execution of the producers and an empirical ratio observed between local and distant processing times may be acquired. For instance, if the local processor and the distant processor are not overloaded with other tasks, this empirical ratio may be close to the frequency ratio between the two processors. To monitor distant execution time, metrics such as distant processing time, distant deserialization time, and distant serialization time may be acquired. To monitor local execution time, metrics such as local execution time, local deserialization time, and local serialization time may be acquired. To monitor data streams, metrics such as size of serialized input objects and size of serialized output objects may be acquired. When processing data on distant processors, input and output data are exchanged over a network. The efficiency of the distant processing is directly linked to the data volume being exchanged. Monitoring the size of data streams may provide useful information to help reduce or avoid overloading the data structures being exchanged with redundant or useless information. To monitor overall execution time, metrics such as the overall time to execute a specific producer may be acquired. In some embodiments, the overall time to execute a specific producer may be the sum of local serialization time, distant deserialization time, distant processing time, distant serialization time, and local deserialization time. This time may be measured on a task-by-task basis, and may be fairly consistent (i.e., the times are very close) across all the tasks pertaining to a single job. To benchmark different types of execution, comparison metrics such as speedup and efficiency may be derived from other metrics acquired. Speedup is a measure of how much a parallel algorithm is faster than a corresponding sequential algorithm. Speedup is defined for a particular job as the sum of local processing times of all tasks (if executed locally) pertaining to the job divided by the job execution time (Job Overall time) using a parallel execution approach, such as multiprocessing. Theoretically, an ideal speedup is reached when speedup substantially equals to the number of processors, that is, when serialization times and deserialization times are close to zero, or compensated by a favorable processor efficiency ratio. The efficiency equals to 100*speedup/number of processors. Again, in a theoretically ideal situation where local and distant processors are identical, the ideal efficiency is close to 100%.

Various techniques have been previously discussed for executing the producers of the producer graph and are applicable here. For instance, in embodiments in which a command log is implemented, the command log is consumed and then the producer graph(s) are executed. Further, in embodiments of the invention that support the possibility of unresolved dependencies, producer graph execution module **1070** includes dynamic dependency module **1075**, which can invoke the automated producer graph generation module **1040**.

FIG. **10** also shows an optional producer graph viewer module **1062** that provides a mechanism (e.g., a GUI) by which a programmer/user can view the producer graph(s) and producer outputs of the producer graph(s) structure. Further, FIG. **10** shows an optional configurable interactive producer output layout graphical user interface module **1085** to provider for a graphical user interface (GUI) (including dynamic invocation of blocks **1030**, and **1035**) that represents the configurable interactive producer output layout graphical user interface module **840**.

In embodiments of the invention that use a command log, different triggers may be use to trigger different actions. For instance, the producer instantiation commands may be logged and batch processed responsive to an explicit command (start logging and end logging), an explicit global execute command (logging starts automatically at startup and after each explicit global execute command, and each log is processed responsive to the following explicit global execute command), an explicit data preparation command, etc. Similarly, the data preparation commands may be logged and batch processed responsive to an explicit global execute command, a first get command, every get command, etc.

Exemplary Tracking Structures

FIGS. **11**A-G are block diagrams illustrating exemplary content of the data structures of FIG. **10** according to one embodiment of the invention. While FIGS. **11**A-G illustrate these data structures as tables, it should be understood that any suitable data structure may be used (e.g., a hash map, a set, a list, etc.).

FIG. **11**A is a block diagram of an example of the class tracking structure **1092** of FIG. **10** according to one embodiment of the invention. In FIG. **11**A, a class key column **1110** and a class reference column **1115** are shown to respectively store the class keys and corresponding references to the loaded classes.

FIG. **11**B is a block diagram of an example of the instance tracking structure **1065** of FIG. **10** according to one embodiment of the invention. In FIG. **11**B, an instance key column **1120** and an instance reference column **1125** are shown to respectively store the instance keys and corresponding references to the instances. In embodiments of the invention in which instance keys need not be unique across all classes, the instance tracking structure also include the class key or reference for the class of the instance

FIG. **11**C is a block diagram of an example of the producer graph(s) structure **1060** of FIG. **10** according to one embodiment of the invention. In FIG. **11**C, a class reference column **1135**, an instance reference column **1140**, and a method reference column **1145** are shown to respectively store references that make up the current producers of the current producer graph(s). These references may take a variety of forms. For example, these columns may respectively store references into the classes **1054** (or alternatively **1092**), instances **1052** (or alternatively **1065**), and methods **1056** (or alternatively **1058**). While in one embodiment of the invention these columns store references, in alternative embodiment of the invention one or more of these columns store keys.

In addition, FIG. **11**C includes a parent producer(s) link(s) column **1150** (including for each link a parent producer reference, and a dependency determination producer reference) and a child producer(s) link(s) column **1160** (including for each link, child producer reference(s), a dependency determination producer reference, a link mode, and a sticky link indicator). Each producer may have zero or more child producer links in column **1160**. Each child producer link in column **1160** includes: 1) child producer reference(s) which are references to other rows of the producer graph(s) structure to represent a producer dependency according to the producer dependency declaration; 2) a dependency determination producer reference which is a reference to another row of the

producer graph(s) structure and represents the dependency determination producer that has created the child link; and 3) a link mode with a producer dependency type that identifies whether the producer dependency is a result of an argument, a field, or a sequencing dependency (see discussion regarding FIGS. **7**A-F), and if an argument, the argument ID of the producer dependency; and 4) a sticky indicator to indicate that the link mode is the result of an upwardly declared dependency (in embodiments of the invention that support upwardly declared dependencies) or the result of a sticky subscription (in embodiments of the invention that support sticky subscriptions) and should not be modified through the producer argument dependency declaration of this producer (i.e., the producer stored in the row of the column containing the sticky indicator). Each producer may have zero or more parent producer links in column **1150**. Each parent producer link in column **1150** includes: 1) a parent producer reference that stores back a reference in accordance with a child producer reference of another producer (i.e., a reference to another row of the producer graph(s) structure to represent a parent producer dependent on this producer); and 2) a dependency determination producer reference which is a reference to another row of the producer graph(s) structure and represents the dependency determination producer which has created the parent link. Thus, when a link is created, the parent producer link column of the child producer's row and the child producer link column of the parent producer's row are modified to represent the link (and the dependency determination producer reference is the same in both). In one embodiment of the invention, since multiple paths in a producer graph or different producer graphs may include a given producer, there may be multiple parent producer links for a given producer.

Further, FIG. **11**C includes a producer output caching and override producer output modification column **1170** to store the current producer outputs, as well as an indication of whether the producer is overridden and the overridden output value. Also, FIG. **11**C includes an incremental execution marking column **1180** to store incremental execution markings as previously described.

In some embodiments, FIG. **11**C includes a producer execution mode setting column **1173** to store the execution mode setting of each producer in the producer graph structure **1060**. For example, the execution mode setting may be one of multiprocessing, multithreading, and local execution.

Further, FIG. **11**C includes a producer metrics column **1175** to store metrics of each producer in the producer graph structure **1060**. The producer metrics are acquired on a producer-by-producer basis using the metrics acquisition module **1082**. Details of some embodiments of the process to acquire metrics are discussed below.

FIG. **11**D is a block diagram of an example of the method tracking structure **1058** of FIG. **10** according to one embodiment of the invention. In FIG. **11**D, a method key column **1190** and a method reference column **1192** are shown to respectively store the method keys and corresponding references to the methods of the loaded classes. In addition, FIG. **11**D also includes an ArgumentDependencies column **1194**, a FieldDependencies column **1196**, a SequencingDependencies column **1195**, an UpwardDependencies column **1193**, a WeaklyConstrainedDependencies column **1199**, an output class column **1197**, and an optional additional annotations column **1198** including a default execution mode. The ArgumentDependencies column **1194**, the SequencingDependencies column **1195**, the UpwardDependencies column **1193**, the WeaklyConstrainedDependencies column **1199**, and the FieldDependencies column **1196** store producer dependency information parsed from the producer dependency declaration statement of the method (e.g., see **705** of FIG. **7**A), while the output class column **1197** stores information regarding the output class of the output of the method (determinable by the method's signature—e.g., see **710** of FIG. **7**A). Exemplary contents of the ArgumentDependencies column **1194**, FieldDependencies column **1196**, SequencingDependencies column **1195**, UpwardDependency column **1193**, and WeaklyConstrainedDependencies column **1199**, used in some embodiments of the invention are provided later herein.

FIG. **11**E is a block diagram of an example of a serialized form local map according to one embodiment of the invention. The serialized form local map in FIG. **11**E includes a serialized form identifier (ID) column **1112**, an input producer key column **1113**, an underlying class key and instance key column **1114**, a serialized form **1116**, a serialized form size **1117**, and a serialization time **1118**. In some embodiments, the serialized form ID, the input producer key, the underlying instance key, and the serialized form are used to implement parallelization by the runtime **1004**. Details of the implementation are discussed below. In some embodiments, the runtime **1004** implements instrumentation to acquire metrics on a producer basis. Thus, the runtime **1004** may store the serialized form size and the serialization time in the columns indicated by dashed lines in the serialized form local map. Details of instrumentation are discussed below.

FIG. **11**F is a block diagram of an example of the runtime setting structure **1048** of FIG. **10** according to one embodiment of the invention. The table includes an original execution mode column **1121** and a final execution mode column **1123**. If an execution mode is not overridden on the runtime global level, the final execution mode is the same as the original execution mode. On the other hand, if the execution mode is overridden on the runtime global level, the final execution mode is different from the original execution mode. For instance, if the runtime **1004** does not support multiprocessing, then multiprocessing may be overridden on the runtime global level by assigning local execution to be the final execution mode of multiprocessing.

FIG. **11**G is a block diagram of an example of the producer-based configuration decision structure **1049** in FIG. **10**. The table includes a class key column **1182**, a method key column **1184**, an instance key column **1186**, an execution mode setting column **1188**. The execution mode selection commands **1036** may modify the execution mode setting in the producer-based configuration decision structure on the basis of a class, a method, an instance, or any combination of the above. Thus, one or more of the class key column **1182**, method key column **1184**, and instance key column **1186** may be empty in a particular row according to one embodiment of the invention.

Distant Computing

As previously described, one embodiment of the invention supports an execution mode of multiprocessing. To support multiprocessing, the runtime may interact with a grid of processors by serializing tasks of producers, as well as inputs and/or an underlying instance of each producers, and sending the serialized form to the grid to be processed by the processors in the grid.

FIG. **12**A is a block diagram illustrating additional detail of FIG. **10** to support multiprocessing according to one embodiment of the invention. To the left of the dashed dividing line **1200** is the runtime with producer graph oriented programming support **1004**. To the right of the dashed dividing line **1200** is a grid **1290**. On the side of the runtime **1004**, FIG. **12**A includes from FIG. **10** the producer graph execution module **1070** (including the parallelization module **1076**, the multiprocessing module **1077**, the multithreading module **1078**,

and the local execution module **1079**) and the grid dispatcher **1081**. On the side of the grid **1290**, FIG. **12**A includes a distant computing module **1270**.

According to one embodiment of the invention, if an execution mode of a producer is multiprocessing, the parallelization module **1076** sends the producer to the multiprocessing module **1077**. The multiprocessing module **1077** may instantiate a job, which may include multiple tasks. The multiprocessing module **1077** may instantiate a task for the producer. The multiprocessing module **1077** may further serialize the task, as well as the inputs to the producer and/or an underlying instance of the producer. Then the multiprocessing module **1077** may add the serialized form of the task to the job. The multiprocessing module **1077** may send the job to the grid dispatcher **1081**. Then the grid dispatcher **1081** may send the job to the distant computing module **1270** of the grid **1290**. Details of the processing of the job by the grid **1290** are discussed below.

After the job has been processed, serialized outputs and/or instances of the tasks within the job are returned to the grid dispatcher **1081**. The grid dispatcher **1081** may forward the serialized outputs and/or instances of the tasks within the job to the multiprocessing module **1077** to be deserialized.

Dynamic Producer Dependencies

As previously described, one embodiment of the invention supports non-dynamic and dynamic producer dependencies. While different embodiments may support different types of dynamic producer dependencies, one embodiment of the invention supports contingent and subscription types of dynamic producer dependencies. Thus, a non-contingent, non-subscription dependency is a non-dynamic (static) dependency.

FIG. **12**B is a block diagram illustrating additional detail of FIG. **10** to support contingent and subscription type dynamic producer dependencies according to one embodiment of the invention. FIG. **12**B includes from FIG. **10** the dashed dividing line **1000**, the class definitions that include business logic **1010** (which include data **1012**, methods **1014**, and producer dependency declarations **1016**), the new class module **1095**, the classes **1054** (including methods and producer dependency declarations **1056**), the new instance module **1098**, the instances **1052**, the instance tracking structure **1065**, the automated producer graph generation module **1040**, the producer graph(s) structure **1060**, and the producer graph execution module **1070** (including the dynamic dependency module **1075**).

FIG. **12**B shows that the producer dependency declarations **1016** optionally include contingent dependencies **1210**, subscription dependencies **1220**, and multiple producers **1215**. Here, multiple producers **1215** refers to the ability of a producer dependency to return a collection of producers. In addition, FIG. **12**B includes a subscription module **1240** and a contingency module **1230** in the automated producer graph generation module **1040** to process the contingent dependencies **1210** and subscription dependencies **1220**. FIG. **12**B also shows that the subscription module **1240** accesses a subscription log **1250**. Further, the dynamic dependency module **1075** includes a contingency module **1260** and a subscription module **1265** to process the contingent dependencies **1210** and subscription dependencies **1220**. The subscription module **1265** accesses the subscription log **1250**.

The following description of contingent and subscription dependencies is done in the context of an embodiment of the invention that uses a class DEP (an abbreviation for dependency), from which an instance is returned by dependency determination producers and is analyzed by the runtime with producer graph oriented programming support. The class DEP includes the following fields: 1) TYPE which can be set to subscription, non-subscription downwardly declared (child producers that are not subscriptions), or non-subscription upwardly declared (parent producers that are not subscriptions); 2) PROD which is used for non-subscription downwardly declared dependencies and is a collection of child producers (as such, it can store zero or more producers); 3) SUB TYPE which is used for subscription dependencies and is set to indicate the type of subscription dependency (used in embodiments of the invention that support multiple types of subscription; while the embodiment of the invention described here can support two types—sticky and absorbing, alternative embodiments may support more, less, and/or different subscription types; 4) SUB CRIT which is used for subscription dependencies and is set to indicate the subscription criteria; 5) PAR LINK MODE which is used for sticky subscription dependencies and non-subscription upwardly declared dependencies and is set to indicate what the link mode of the parent producer should be; 6) PAR CLASS which is used for sticky subscription dependencies and non-subscription upwardly declared dependencies and is set to indicate what the class of the parent producer (e.g., the class key) should be; 7) PAR METHOD which is used for sticky subscription dependencies and non-subscription upwardly declared dependencies and is set to indicate what the method of the parent producer (e.g., the method key) should be; and 8) PAR INSTANCE which is used for sticky subscription dependencies and non-subscription upwardly declared dependencies and is set to indicate what the instance of the parent producer (e.g., the instance key) should be (If PAR INSTANCE is left blank, the instance key of the child producer is then used for the parent producer). An alternative embodiment could use a collection of parent producers (each item of the collection holding a PAR_CLASS, PAR_INSTANCE, PAR_METHOD, PAR_LINK MODE) in the case of sticky subscription dependencies and/or non-subscription upwardly declared dependencies. Of course, other alternative embodiments of the invention could use a different structure to return dependencies.

Contingent Dependencies

In one embodiment of the invention, both non-contingent and contingent producer dependencies are supported. A non-contingent producer dependency is one that is independent of the output of other producers, while a contingent producer dependency is one that is dependent on the output of other producers. While one embodiment of the invention supports both non-contingent and contingent producer dependencies, alternative embodiments support only non-contingent or contingent (which contingent producer dependencies may be initially driven by default values).

As previously discussed, a producer can be viewed as a set of multiple identifiers, one identifier for each additional level of granularity specified. In one embodiment of the invention, a contingent producer dependency can be contingent in the sense that any one or all of the set of identifiers can be conditionally determined based on current data values. For instance, a first contingent producer dependency may have only the instance identifier be conditionally determined (the class and method identifiers are fixed), while a second contingent producer dependency may have the class, instance, and method identifiers be conditionally determined. While in one embodiment of the invention, all of the plurality of identifiers of a contingent producer dependency may be conditional, alternative embodiments of the invention may be implemented differently (e.g., only allow a subset of the plurality of identifiers to be conditional).

FIGS. **13**A-J are block diagrams illustrating pseudo code and exemplary producers according to one embodiment of the invention. In addition, the embodiments shown in FIG. **13**A-J use the same dependency determination mechanism for both contingent and non-contingent dependencies. As such, for explanation purposes, some of the examples in FIGS. **13**A-J are examples of non-contingent dependencies, while the others are examples of contingent producer dependencies. Further, a non-contingent producer dependency is one in which the dependency is to a dependency determination producer that is an independent producer (e.g., in one embodiment of the invention, the dependency type is identifiable because its producer dependency declaration is empty); while a contingent producer dependency is one in which the dependency is to a dependency determination producer that is a dependent producer (e.g., in one embodiment of the invention, the dependency type is identifiable because its producer dependency declaration is non-empty).

Further, circled numbers and letters are used in FIGS. **13**A-J to illustrate the order in which operations are performed according to one embodiment of the invention. Also, a notation X::Y::Z is used in FIGS. **13**A-J to represent a producer key made up of a class key (X), an instance key (Y), and a method key (Z). Further dashed circles and arrowed lines represent operations that are not performed in some embodiments of the invention. In particular, where the execution of an independent dependency determination producer for a given dependency will always return the same dependency (e.g., an independent dependency determination producer), such dependency determination producer in some embodiments of the invention is executed but not instantiated and linked in the producer graph(s).

Explicit Dependency Determination Producers

FIG. **13**A illustrates pseudo code of producer dependency declarations for methods using a non-shortcut declared, non-dynamic (non-contingent, non-subscription) dependency according to one embodiment of the invention; while FIG. **13**B is a block diagram of producers illustrating an exemplary non-shortcut declared, non-dynamic (non-contingent, non-subscription) producer dependency according to one embodiment of the invention. FIG. **13**A shows: 1) a producer dependency declaration statement **1300** for a method alpha **1305**, where the producer dependency declaration statement **1300** includes a producer dependency to a producer CW::IY::BETA; and 2) a producer dependency declaration statement **1310** for a method beta **1315**, where the producer dependency declaration statement **1310** is empty, and where the method beta **1315** returns as an argument an instance of the class DEP. The method beta **1315** includes producer dependency declaration code **1320** that sets DEP.TYPE to non-subscription downwardly declared, sets DEP.PROD to producer **13**, and returns DEP.

In FIG. **13**A, a circled **1** indicates that the producer dependency declaration **1300** is accessed (e.g., as a result of designation of a producer based on the method alpha **1305** as a producer of interest, as a result of automated discovery of a producer based on the method alpha **1305**, as a progeny of a producer of interest, etc.). A circled **2** in FIG. **13**B shows that a producer C**0**::I**0**::ALAPHA is instantiated based on the method alpha **1305**. A circled **3** in FIG. **13**A indicates that the producer dependency to producer CW::IY::BETA is processed to determine the producer dependency, and as a result, a circled **4** indicates that the producer dependency declaration **1310** is accessed. A dashed circled **5** in FIG. **13**B shows that a producer CW::IY::BETA is instantiated as a dependency determination producer **1380**. A dashed circled **6** in FIG. **13**B indicates that the producer C**0**::I**0**::ALPHA is linked in the producer graph to indicate that producer CW::IY::BETA is a child producer. A circled **7** in FIG. **13**B indicates that the producer CW::IY::BETA is executed and returns DEP to identify producer **13**. A circled **8** indicates producer **13** is instantiated, while a circled **9** indicates the producer **13** being linked as a child producer in the producer graph to the producer C**0**::I**0**::ALPHA. In FIG. **13**B, producer C**0**::I**0**::ALPHA and producer **13** are standard producers **1385** (they are not dependency determination producers).

FIG. **13**C illustrates pseudo code of producer dependency declarations for methods using a non-shortcut declared, contingent, non-subscription producer dependency according to one embodiment of the invention; while FIG. **13**D is a block diagram of producers illustrating an exemplary non-shortcut declared, contingent, non-subscription producer dependency according to one embodiment of the invention. In addition, FIG. **13**D refers to the producers **5**, **7**A, and **7**B of FIG. **5**A and the resolution of the dynamic dependency of producer **5** to the producer **7**A.

FIG. **13**C shows: 1) a producer dependency declaration statement **1300** for a method alpha **1305**, where the producer dependency declaration statement **1300** includes a producer dependency to a producer CW::IY::BETA; 2) a producer dependency declaration statement **1325** for a method beta **1315**, where the producer dependency declaration statement **1325** includes a producer dependency to a producer CU::IV::DELTA, and where the method beta **1315** returns as an argument an instance of the class DEP; 3) a producer dependency declaration statement **1332** for a method delta **1334**, where the producer dependency declaration statement **1332** is empty, and where the method delta **1334** returns as an argument an instance of the class DEP; and 4) a producer dependency declaration statement **1338** for a method gamma **1340**, where the producer dependency declaration statement **1338** is empty, and where the method gamma **1340** returns a variable X (where X is from an external source, a default value (explicit or constant in the class). The method beta **1315** includes producer dependency declaration code **1330** that sets DEP.TYPE to non-subscription downwardly declared, sets DEP.PROD to producer **7**A or **7**B depending on the output of producer CX::IZ::GAMMA, and returns DEP. The method delta **1332** includes producer dependency declaration code **1336** that sets DEP.TYPE to non-subscription downwardly declared, sets DEP.PROD to the producer CX::IZ::GAMMA, and returns DEP.PROD.

In FIG. **13**C, a circled **1** indicates that the producer dependency declaration **1300** is accessed (e.g., as a result of designation of a producer based on the method alpha **1305** as a producer of interest, as a result of automated discovery of a producer based on the method alpha **1305** as a progeny of a producer of interest, etc.). A circled **2** in FIG. **13**D shows that the producer **5** is instantiated based on the method alpha **1305**. A circled **3** in FIG. **13**C indicates that the producer dependency to producer CW::IY::BETA is processed to determine the producer dependency, and as a result, a circled **4** indicates that the producer dependency declaration **1325** is accessed. A circled **5** in FIG. **13**D shows that a producer CW::IY::BETA is instantiated as a dependency determination producer **1380**. A circled **6** in FIG. **13**D indicates that the producer **5** is linked in the producer graph to indicate that producer CW::IY::BETA is a child producer.

A circled **7** in FIG. **13**C indicates that the producer dependency to producer CU::IV::DELTA is processed to determine the producer dependency, and as a result, a circled **8** indicates that the producer dependency declaration **1332** is accessed. A dashed circled **9** in FIG. **13**D shows that a producer CU::IV::DELTA is instantiated as a dependency determination pro-

ducer **1380**. A dashed circled **10** in FIG. **13**D indicates that the producer CW::IY::BETA is linked in the producer graph to indicate that producer CU::IV::DELTA is a child producer. A circled **11** in FIG. **13**D indicates that the producer CU::IV::DELTA is executed and returns DEP to identify CX::IZ::GAMMA. A circled **12** indicates that the producer CX::IZ::GAMMA is instantiated, while a circled **13** indicates the producer CX::IZ::GAMMA being linked as a child producer in the producer graph to the producer CW::IY::BETA.

In FIG. **13**D, a circled A indicates that the producer CX::IZ::GAMMA is executed and returns X to producer CW::IY::BETA, while a circled B indicates that the producer CW::IY::BETA returns DEP to identify producer **7**A; a circled C indicates that the unresolved remainder (method beta) **1390** is now resolved and producer **7**A is instantiated, while a circled D indicates the linking of the producer **5** to the producer **7**A. In FIG. **13**D, producers CX::IZ::GAMMA, **5**, and **7**A are standard producers **1385**.

On the Fly Dependency Determination Producers

FIG. **13**E illustrates pseudo code of producer dependency declarations for methods using both a non-shortcut declared, contingent, non-subscription producer dependency and a shortcut declared, contingent, non-subscription producer dependency according to one embodiment of the invention; while FIG. **13**F is a block diagram of producers illustrating a non-shortcut declared, contingent, non-subscription producer dependency and a shortcut declared, contingent, non-subscription producer dependency according to one embodiment of the invention. Similar to FIGS. **13**D, FIG. **13**F refers to the producers **5**, **7**A, and **7**B of FIG. **5**A and the resolution of the dynamic dependency of producer **5** to the producer **7**A.

FIGS. **13**E-F are the same as FIGS. **13**C-D, with the exceptions: 1) a producer dependency declaration statement **1342** replaces the producer dependency declaration statement **1325**; 2) a method fly **1344** replaces the method delta **1334**; and 3) a producer CW::IY::FLY replaces the producer CU::IV::DELTA. The producer dependency declaration statement **1342** includes a shortcut declared producer dependency to the CX::IZ::GAMMA. Thus, the circled **4** in FIG. **13**E now indicates that the producer dependency declaration **1342** is accessed. The circled **7** in FIG. **13**E now indicates that the shortcut declared producer dependency to producer CX::IZ::GAMMA is processed to determine the producer dependency, and as a result, the runtime invokes the dependency determination producer CW::IY::FLY on the fly based on the method fly **1344**. The circled **8** now indicates that the producer dependency declaration **1332** is accessed. The dashed circled **9** in FIG. **13**F now shows that the producer CW::IY::FLY is instantiated. The dashed circled **10** in FIG. **13**F indicates that the producer CW::IY::BETA is linked in the producer graph to indicate that producer CW::IY::FLY is a child producer. The circled **11** in FIG. **13**F indicates that the producer CW::IY::FLY is executed and returns DEP to identify CX::IZ::GAMMA. The remainder of FIGS. **13**E-F is the same as FIGS. **13**C-D.

The on the fly generation by the runtime of the dependency determination producer CW::IY::FLY alleviates the application programmer from having to write explicit producer dependency declaration code and instantiate a dependency determination producer based thereon. Further, it allows the application programmer to directly specify the dependency on producer CX::IZ::GAMMA in the producer dependency declaration statement for the method beta **1315**, as opposed to specifying the dependency determination producer CU::IV::DELTA.

The shortcut technique can be used in a variety of situations, and may additionally have a variety of formats. For example, while in FIGS. **13**E-F the shortcut declared dependency is for a non-contingent dependency (it directly identifies the child producer) and is in a producer dependency declaration statement for a method on which a dependency determination producer is based, other situations and formats are shown as follows: 1) FIGS. **13**G-H illustrate the use of two shortcuts, where one is contingent and is part of a producer dependency declaration statement for a method on which a standard producer is based and the other is non-contingent and is part of a producer dependency declaration statement for a method on which a dependency determination producer is based; and 2) FIGS. **13**I-J illustrate the use of a shortcut that is non-contingent and that is in a producer dependency declaration statement for a method on which a parent standard producer is based.

FIG. **13**G illustrates pseudo code of producer dependency declarations for methods using a shortcut declared, contingent, non-subscription producer dependency and a shortcut declared, non-contingent, non-subscription producer dependency according to one embodiment of the invention; while FIG. **13**H is a block diagram of producers illustrating an exemplary shortcut declared, contingent, non-subscription producer dependency and a shortcut declared, non-contingent, non-subscription producer dependency according to one embodiment of the invention. FIG. **13**G shows: 1) a producer dependency declaration statement **1345** for the method alpha **1305**, where the producer dependency declaration statement **1345** includes a shortcut declared, contingent producer dependency to a producer <P>GETC**1**::I**1**::M**1**; 2) a producer dependency declaration statement **1350** for a method fly**1** **1355**, where the producer dependency declaration statement **1350** includes a shortcut declared, non-contingent producer dependency to a producer C**0**::I**0**::GETC**1**, and where the method fly**1** **1355** returns as an argument an instance of DEP; 3) the producer dependency declaration statement **1332** for a method fly**2** **1362**, where the method fly**2** **1362** returns as an argument an instance of DEP; and 4) the producer dependency declaration statement **1365** for a method getc**1** **1370**, where the method getc**1** **1370** returns C**1** with a value of CX or CY.

The method FLY**1** **1355** and its producer dependency declaration statement **1350** are provided by the runtime responsive to the shortcut declared dependency <P>GETC**1**::I**1**::M**1** (which indicates that the shortcut is being used for the class key). The method fly**1** **1355** includes producer dependency declaration code **1360** that sets DEP.TYPE to non-subscription downwardly declared, sets DEP.PROD to producer CX::I**1**::M**1** or CY::I**1**::M**1** depending on the value of C**1** output by the producer C**0**::I**0**::GETC**1**, and returns DEP. While in the example of FIG. **13**H, a <P> is used to designate that it is the class key of the producer that is contingent, alternative embodiments of the invention could use other syntaxes. Further, while in the example of FIG. **13**H, a <P> is used to designate that it is the class key of the producer that is contingent, one embodiment of the invention supports having more and/or different ones of the identifiers that make up the producer key be indicated as contingent in this manner.

In FIG. **13**G, a circled **1** indicates that the producer dependency declaration **1345** is accessed (e.g., as a result of designation of a producer based on the method alpha **1305** as a producer of interest, as a result of automated discovery of a producer based on the method alpha **1305** as a progeny of a producer of interest, etc.). A circled **2** in FIG. **13**H shows that the producer C**0**::I**0**::ALPHA is instantiated based on the method alpha **1305**. A circled **3** in FIG. **13**G indicates that the shortcut declared producer dependency is processed to determine the producer dependency and the runtime provides the

method fly1 1355; and as a result, a circled 4 indicates that the producer dependency declaration 1350 is accessed.

A circled 5 in FIG. 13H shows that a producer C0::I0::FLY1 is instantiated as a dependency determination producer 1380. A circled 6 in FIG. 13H indicates that the producer C0::I0::ALPHA is linked in the producer graph to indicate that producer C0::I0::FLY1 is a child producer. A circled 7 in FIG. 13G indicates that the shortcut declared producer dependency to producer C0::I0::GETC1 is processed to determine the producer dependency and the runtime provides the method fly2 1362, and as a result, a circled 8 indicates that the producer dependency declaration 1332 is accessed. A dashed circled 9 in FIG. 13H shows that a producer C0::I0::FLY2 is instantiated. A dashed circled 10 in FIG. 13H indicates that the producer C0::I0::FLY1 is linked in the producer graph to indicate that producer C0::I0::FLY2 is a child producer.

A circled 11 in FIG. 13H indicates that the producer C0::I0::FLY2 is executed and returns DEP to identify producer C0::I0::GETC1. A circled 12 indicates that the producer C0::I0::GETC1 is instantiated, while a circled 13 indicates that the producer C0::I0::GETC1 being linked in the producer graph to the producer C0::I0::FLY1 as a child producer.

In FIG. 13H, a circled A indicates that the producer C0::I0::GETC1 is executed and returns C1=CX to producer C0::I0::FLY1, while a circled B indicates that the producer C0::I0::FLY1 is executed and returns DEP to identify producer CX::I1::M1; a circled C indicates that the unresolved remainder (method fly1) 1390 is now resolved, and a circled D indicates the linking of the producer C0::I0::ALPHA to the producer CX::I1::M1. In FIG. 13H, producers C0::I0::GETC1, C0::I0::ALPHA, and CX::I1::M1 are standard producers 1385.

The on the fly generation by the runtime of the dependency determination producer C0::I0::FLY1 and C0::I0::FLY2 alleviates the application programmer from having to write explicit producer dependency declaration code and instantiate dependency determination producers based thereon. Further, it allows the application programmer to directly specify the contingent dependency on a producer **::I1::M1 through the method getC1 in the producer dependency declaration statement for the method alpha 1305, as opposed to specifying the dependency determination producer CW::IY::BETA.

FIG. 13I illustrates pseudo code of producer dependency declarations for methods using a shortcut declared, non-dynamic (non-contingent, non-subscription) producer dependency according to one embodiment of the invention; while FIG. 13J is a block diagram of producers illustrating an exemplary shortcut declared, non-dynamic producer dependency according to one embodiment of the invention. FIG. 13I shows: 1) a producer dependency declaration statement 1372 for a method alpha 1305, where the producer dependency declaration statement 1372 includes a shortcut declared producer dependency to a producer 10; and 2) a producer dependency declaration statement 1374 for a method fly 1376, where the producer dependency declaration statement 1374 is empty, and where the method fly 1376 returns as an argument an instance of DEP. The method fly 1776 and its producer dependency declaration statement 1374 are provided by the runtime responsive to the shortcut declared dependency. The method fly 1376 includes producer dependency declaration code 1378 that sets DEP.TYPE to non-subscription downwardly declared, sets DEP.PROD to producer 10, and returns DEP.

In FIG. 13I, a circled 1 indicates that the producer dependency declaration 1372 is accessed (e.g., as a result of designation of a producer based on the method alpha 1305 as a producer of interest, as a result of automated discovery of a producer based on the method alpha 1305 as a progeny of a producer of interest, etc.). A circled 2 in FIG. 13J shows that a producer C0::I0::ALPHA is instantiated based on the method alpha 1305. A circled 3 in FIG. 131 indicates that the shortcut declared producer dependency is processed to determine the producer dependency and the runtime provides the method fly 1376; and as a result, a circled 4 indicates that the producer dependency declaration 1374 is accessed. A dashed circled 5 in FIG. 13J shows that a producer C0::I0::FLY is instantiated as a dependency determination producer 1380. A dashed circled 6 in FIG. 13J indicates that the producer C0::I0::ALPHA is linked in the producer graph to indicate that producer C0::I0::FLY is a child producer.

A circled 7 in FIG. 13J indicates that the producer C0::I0::FLY is executed and returns DEP to identify producer 10. A circled 8 indicates producer 10 is instantiated, while a circled 9 indicates the producer C0::I0::ALPHA being linked in the producer graph to indicate that producer 10 is a child producer. In FIG. 13J, producer C0::I0::ALPHA and producer 10 are standard producers 1385.

It should be understood that the runtime programmer, in one embodiment of the invention, writes a single fly method to interpret all supported syntaxes and combinations (e.g., the method fly 1334, the method fly1 1355, the method fly2 1362, the method fly 1376) and includes it in the runtime. This not only allows applications programmers to avoid writing code for dependency determination producers where a fly method may be used, the runtime programmer need only write the generic fly method (the single fly for all supported situations) once. Further, it should be understood that shortcut declared dependencies allow for a runtime that uses dependency determination producers while at the same time allowing an application programmer to indicate standard producers in the producer dependency declarations (e.g., FIGS. 13G-J).

Method Tracking Structure

Referring back to the method tracking structure of FIG. 11D, exemplary contents of the ArgumentDependencies column 1194, FieldDependencies column 1196, SequencingDependencies column 1195, UpwardDependencies column 1193, and WeaklyConstrainedDependencies column 1199 used in some embodiments of the invention will now be described. Specifically, the ArgumentDependencies column 1194 stores a collection of items, one for each ArgumentDependency. In one embodiment of the invention, each item includes the following: 1) the argument ID; 2) a class key nature identifier, being one of explicit class, same class, and contingent class; 3) an explicit class key identifier populated when the class key nature identifier indicates explicit class; 4) contingent class determination method key identifier populated when the class key nature identifier indicates contingent class; 5) an instance key nature identifier, being one of explicit instance, same instance, and contingent instance; 6) an explicit instance key identifier populated when the instance key nature identifier indicates explicit instance; 7) contingent instance determination method key identifier populated when the instance key nature identifier indicates contingent instance; 8) a method key nature identifier, being one of explicit method, same method, and contingent method; 9) an explicit method key identifier populated when the method key nature identifier indicates explicit method; 10) contingent method determination method key identifier populated when the method key nature identifier indicates contingent method; and 11) a shortcut identifier that indicates if the producer dependency declaration for the argument in the producer dependency declaration statement contained an indication of shortcut (i.e., the producer dependency declaration statement

directly identifies a standard child producer instead of a dependency determination producer).

The " . . . explicit" indication of the various key nature identifiers is used where the explicit key is provided for the producer dependency in the producer dependency declaration statement. By way of example, the producer dependency "CW::IY::BETA" of the producer dependency declaration statement **1300** of FIG. **13**A provides an explicit class, instance, and method key.

In some embodiments of the invention, a shorthand technique is supported for the producer dependency declaration statements such that: 1) if a class is not provided for a given producer dependency, then the same class as the parent producer is used; and 2) if a class and instance are not provided for a given producer dependency, then the same class and instance as the parent producer are used. In other embodiments of the invention, a syntax is used to allow any combination of class, instance, and method, to be the same as the parent (with the exception of all being the same) (e.g., a separator is used to designate each of class, instance, and method, and an absence of such a separator indicates same as parent—by way of specific example, the syntax may be "#C:", "#I:", and "#M:", such that a producer dependency in a producer dependency declaration statement may be #C:"class key"::#I:"instance key"::#M:"method key".) (where quotes indicate a placeholder for a value or variable) The " . . . same" indication of the various key nature identifiers is used where this shorthand technique is used in the producer dependency declaration statement.

As previously indicated, in some embodiments of the invention an indication of a contingent producer dependency is supported through a syntax (e.g., <P>) used in the producer dependency declaration statement itself (see **1345** of FIG. **13**G), and such syntax can be used on one or more of the class, instance, and method of a producer dependency. The " . . . contingent" indication of the various key nature identifiers is used to identify when such a contingent producer dependency occurs, while the "contingent . . . determination method key identifier" indicates the method key of the child producer (the class and the instance are the same as that of the parent producer). By way of example, the producer dependency "<P>GETC**1**::I**1**::M**1**" for the producer dependency declaration **1345** of FIG. **13**G provides a contingent class (where the contingent class determination method key is GETC**1**), an explicit instance key, and an explicit method key.

The SequencingDependencies column **1195**, the UpwardDependencies column **1193**, and the WeaklyConstrainedDependencies column **1195** each store a collection of items, one for each SequencingDependency, UpwardDependency, and WeaklyConstrainedDependency. In one embodiment of the invention, each such item has the same structure as an item of the collection for the ArgumentDependencies, except that it does not include an argument ID. Further, although FIGS. **13**A-J illustrated non-subscription downwardly declared dependencies originating from dependency determination producers, it should be understood that in the case of an upwardly declared dependency or weakly constrained dependency the dependency determination producer may return the other dependencies discussed with reference to FIG. **7**F-G.

The FieldDependencies column **1196** stores a collection of items, one for each FieldDependency. While in one embodiment of the invention each item includes the property method key, in alternative embodiments of the invention may have the same structure as an item of the collection from SequencingDependencies.

Subscription Dependencies

In one embodiment of the invention, both non-subscription and subscription producer dependencies are supported. When a subscription producer dependency is declared for a given method and a given producer is instantiated from that given method, the runtime can resolve during run time (based upon the existence of other producers) the set of zero or more producers that meet the criteria of the subscription. While one embodiment of the invention supports both non-subscription and subscription producer dependencies, alternative embodiments support only non-subscription. In addition, while in one embodiment of the invention two types of subscription dependencies are supported (absorbing and sticky), alternative embodiments of the invention support more, less, and/or different types of subscription producer dependencies.

FIGS. **14**A-C are block diagrams illustrating absorbing and sticky subscriptions according to one embodiment of the invention. FIG. **14**A is a block diagram of an example of the subscription log **1250** of FIG. **12**B according to one embodiment of the invention. While FIG. **14**A illustrates this log structure as a table, it should be understood that any suitable data structure may be used (e.g., a hash map). FIG. **14**B is a block diagram of exemplary producers illustrating a non-contingent, absorbing subscription producer dependency according to one embodiment of the invention. FIG. **14**C is a block diagram of exemplary producers illustrating a non-contingent, sticky subscription producer dependency according to one embodiment of the invention. Two rows are shown in the table of FIG. **14**A populated with content used in the examples of FIGS. **14**B-C. Circled numbers are used in FIGS. **14**B-C to illustrate the order in which operations are performed according to one embodiment of the invention.

In FIG. **14**A, a subscriber's producer key column **1400**, a subscription type column **1405**, and a subscription criteria for trigger producers column **1410** are shown to respectively store the content corresponding to the column name. In addition, FIG. **14**A shows a parent link modecolumn **1425** to store the link mode for the parent producer of the subscription dependency; this information will be described in more detail with regard to FIGS. **14**B-C.

FIG. **14**A also shows a matching producers column **1415** and a completed column **1420** used for absorbing subscriptions. The matching producers column **1415** is used to store the producer keys of the trigger producers that meet the subscription criteria of the absorbing subscription, while the completed column **1420** is used to track whether the absorbing subscription has been completed during a given execution of the current set of producer graphs. The matching producers column **1415** and the completed column **1420** provide an additional optional optimization that allows for the work of scanning the instantiated producers to be divided between the automated producer graph generation and the producer graph execution as described later herein.

FIG. **14**A also shows a parent class column **1430**, a parent method column **1435**, and a parent instance column **1437** used for sticky subscriptions. The parent class column **1430**, the parent method column **1435**, and the parent instance column **1437** respectively store the class key, method key, and instance key of the parent producer to be created for the sticky subscription. In addition, FIG. **14**A shows a dependency determination producer reference column **1421** store a reference to the dependency determination producer creates the subscription.

Absorbing Subscription

In an absorbing subscription producer dependency, the dependency is to the collection of all producers of the current producer graph structure that meet the absorbing subscription

criteria. With reference to FIG. **14**B, a circled **1** indicates a producer **1450** is instantiated (e.g., as a result of designation of the producer **1450** as a producer of interest, as a result of automated discovery of the producer **1450** as a progeny of a producer of interest, etc.). The producer **1450** is based on a method for which the producer dependency declaration includes a producer dependency (e.g., with argument ID X). A circled **2** indicates the producer dependency of the producer **1450** is processed to identify a producer **1455**.

A circled **3** indicates that the producer **1450** is linked (in the above example, through argument ID X) in the producer graph to producer **1455** as a child producer. A circled **4** indicates execution of the producer **1455**. The producer **1455** is a dependency determination producer that includes producer dependency declaration code indicating an absorbing subscription producer dependency and indicating the absorbing subscription criteria. As such, the execution of the producer **1455** results in populating the subscription log. With regard to the example in the first row of FIG. **14**A, the subscriber's producer key column **1400**, the subscription type column **1405**, the subscription criteria for trigger producers column **1410**, the parent link mode column **1425**, and the dependency determination producer reference column **1421** are respectively populated with the producer key of the producer **1450**, an indication that the subscription is of the absorbing type, the absorbing subscription criteria contained within the producer **1455**, the link mode of the producer **1450** linked to the producer **1455** (which, in the case of an absorbing subscription will be an argument dependency and include an argument ID, but whose sticky indicator will indicate not sticky—in the above example, argument ID X), and a reference to the producer **1455** (the dependency determination producer that cerates the subscription).

Circled **5**A-N indicates the instantiation of producers **1460**A-N. In this example, the producers **1460**A-N meet the absorbing subscription criteria, and thus are trigger producers. As such, circled **6**A-N indicates the linking of the producer **1450** to the producers **1460**A-N (in the above example, through argument ID X). A circled **7** indicates that the absorbing subscription dependency is completed for the current execution of the producer graph(s), and the producer **1450** is then executed.

In one embodiment of the invention, the absorbing subscription criteria can be one or more of any of the keys making up a producer key. Thus, in embodiments of the invention where a producer key comprises a class key, instance key, and a method key, the subscription criteria could be one or more such keys. By way of example with reference to FIG. **11**C, a scan through the instantiated producers for those that meet the subscription criteria is a scan through one or more of the first three columns of the producer graph(s) structure to determine if the keys of the instantiated producers match the keys of the absorbing subscription criteria. While in one embodiment of the invention the absorbing subscription criteria can be one or more of any of the keys making up a producer key, in alternative embodiments of the invention the absorbing subscription criteria is limited to a subset of the keys making up a producer key.

Sticky Subscription

In a sticky subscription producer dependency, the dependency causes a parent producer to be instantiated for each producer that meets the sticky subscription criteria. With reference to FIG. **14**C, a circled **1** indicates a producer **1470** is instantiated (e.g., as a result of designation of the producer **1470** as a producer of interest, as a result of automated discovery of the producer **1470** as a progeny of a producer of interest through a sequencing dependency (e.g., as a result of a SequencingDependency or WeaklyConstrainedDependency, etc.). The producer **1470** is a dependency determination producer that includes producer dependency declaration code indicating a sticky subscription, the sticky subscription criteria for the trigger producers, and the sticky subscription characteristics for the parent producer to be created.

Execution of the producer **1470** results in populating the subscription log. With regard to the example in the second row of FIG. **14**A, the subscriber's producer key column **1400**, the subscription type column **1405**, and the subscription criteria for trigger producers column **1410** are respectively populated with the producer key of the producer **1470**, an indication that the subscription is of the sticky type, and the sticky subscription criteria for the trigger producers contained within the producer **1470**. In addition, the parent class column **1430**, the parent method column **1435**, the parent instance column **1437**, and the link mode column **1425** of the parent producer to be linked to the trigger producer are populated with the sticky subscription characteristics for the parent producer to be created—in this embodiment of the invention, respectively the class of the parent producer to be instantiated, the method of the parent producer to be instantiated, the instance of the parent producer to be instantiated (if left blank, would be equal to the instance key of the trigger producer), the link mode (which, in the case of sticky subscription, may be: 1) argument, field, or sequencing dependency; 2) argument ID if an argument dependency—the argument ID of the parent producer to be linked to the trigger producer (e.g., argument ID Y). In addition, the dependency determination producer reference column **1421** is populated with a reference to the dependency determination producer that created the subscription (in FIG. **14**C, the producer **1470**).

With reference to FIG. **14**C, a circled **2** indicates a producer **1475** is instantiated (e.g., as a result of designation of the producer **1475** as a producer of interest, as a result of automated discovery of the producer **1475** as a progeny of a producer of interest, etc.). In addition, it is determined if the producer **1475** meets the sticky subscription criteria for a trigger producer. A circled **3** indicates that responsive to the trigger producer **1475**, a producer **1480** is instantiated based on the sticky subscription characteristics for the parent producer to be created. With reference to the exemplary second row of FIG. **14**C, the class key, method key, instance key, and link mode are accessed from the parent class column **1430**, the parent method column **1435**, the instance column **1437**, and the parent link mode column **1425**, respectively. The parent producer has a producer key comprising the accessed class key, the accessed instance key (if left blank, the instance key of the trigger producer (in FIG. **14**C, the producer **1475**)), and the accessed method key—in the example of FIG. **14**C, this is producer **1480**. A circled **4** indicates that the instantiated parent producer **1480** is linked in the producer graph to the child trigger producer **1475** through the accessed link mode (in the above example, link mode type=argument dependency; link mode argument ID=Y). Also at circled **4**, in the case of an argument dependency, the sticky indicator is set to indicate sticky—that the producer dependency in that position of the producer dependency declaration statement for the method on which the instantiated parent producer **1480** is based should be ignored for the producer **1480**—this prevents the link created by the sticky subscription producer dependency from being overwritten by later automated producer graph generation operations

In one embodiment of the invention, the sticky subscription criteria for trigger producers can be one or more of the keys making up a producer key. Thus, in embodiments where a

producer key comprises a class key, instance key, and a method key, the sticky subscription criteria for the trigger could be one or more of the class, instance, and method keys. By way of example with reference to FIG. **11**C, a scan through the instantiated producers for those that meet the sticky subscription criteria for trigger producers is a scan through one or more of the first to third columns of the producer graph(s) structure to determine if the keys of the instantiated producers match the keys of the sticky subscription criteria for trigger producers. While in one embodiment of the invention the sticky subscription criteria for trigger producers can be one or more of the keys making up a producer key, in alternative embodiments of the invention the absorbing subscription criteria can be a more limited number of the keys making up a producer key.

FIGS. **14**D-E illustrate the choice of a parent producer based upon a parent dependency determination producer according to one embodiment of the invention. While FIGS. **14**D-E are described with reference to argument dependencies, embodiments of the invention may support the use of sequencing and field dependencies.

FIG. **14**D illustrates the choice of a parent producer based upon a parent dependency determination producer created by a sticky subscription according to one embodiment of the invention. Like FIG. **14**C, FIG. **14**D shows the sticky subscription producer **1470** and the trigger producer **1475**; however, rather than the producer **1480**, FIG. **14**D shows a dependency determination producer **1480** created through the sticky subscription of sticky subscription producer **1470**. Further, FIG. **14**D shows that the link mode of the sticky subscription is argument dependency, argument ID=X, and sticky indicator=sticky. As illustrated by the dashed curved line from the producer **1475** to the dependency determination producer **1480**, the DEP returned by the dependency determination producer may be based on the output of the producer **1475** itself (the argument of argument ID=X). In FIG. **14**D, the dependency determination producer **1480** returns an non-subscription upwardly declared producer dependency on a producer **1482**, with the link mode indicating argument dependency and argument ID=Y. While the argument IDs of X and Y are used in FIG. **14**D to show that they may differ, it should be understood that they may be equal.

FIG. **14**E illustrates the choice of a parent producer based upon a parent dependency determination producer created by a child dependency determination producer, which child dependency determination producer is linked by a sequencing dependency, according to one embodiment of the invention. FIG. **14**E is similar in structure to FIG. **14**D; specifically, the producer **1475**, **1480**, and **1482** are replaced with producers **1486**, **1496**, and **1498**. However, rather than the sticky subscription producer **1470** creating the link between the producers **1480** and **1475**, the producer **1486** has a sequencing dependency on a dependency determination producer **1494** (e.g., created through an UpwardDependency or a WeaklyConstrainedDependency), which creates the dependency determination producer **1496** through a non-subscription upwardly declared dependency.

It is worth nothing that sticky subscriptions and non-subscription upwardly declared dependencies (e.g., created through UpwardDependencies and/or WeaklyConstrainedDependencies) cause a bottom up building of a producer graph (as opposed to the top down building described earlier herein). Further, this bottom up building is not limited to the building of a single level, but may be multiple level (e.g., if, due to a sticky subscription or non-subscription upwardly declared dependency, a parent producer is instantiated, that same parent producer may also be a trigger producer for a sticky subscription or may include a non-subscription upwardly declared dependency and cause the instantiation of another parent producer, and so on). In this sense, sticky subscriptions, as well as non-subscription upwardly declared dependencies, reverse producer graph building.

While in some embodiments of the invention the parent producers identified by the sticky subscription characteristics are standard producers (see FIG. **14**C), alternative embodiments may be implemented to support the identification of other types of producers. For example, in embodiments of the invention that allow the sticky subscription characteristics to identify a dependency determination producer (see FIG. **14**D), such a dependency determination producer may access the output of the trigger producer and may, based on that output, trigger the creation of a particular producer as a parent producer that needs to stick on the child (this parent producer might already exist or not; If it already exists, it is simply linked, and the child producer is added to its argument; If is does not exist yet, it is created). The case where the dependency determination producer returns a constant producer mimics an absorbing subscription. The case where the dependency determination producer returns a producer whose instance key is unique per trigger producer (e.g., returns a producer whose instance key is the producer key of the trigger producer) results in a separate parent producer per child producer and is referred to as a pure sticky subscription. The case where the dependency determination producer returns an instance key which is neither constant nor unique per trigger producer can mix the behaviors of pure sticky subscriptions and absorbing subscriptions and is referred to as a non-pure sticky subscription.

Exemplary Advantages

As previously described, in one embodiment of the invention, producer dependencies are declared for methods as a way to specify method invocation sequencing using the appropriate instances (where the appropriate instances include the instances to use as arguments, the instances to be used by instance methods, and the meta class instances used by class methods) without using manual invocation sequencing code; effectively, the work of generating some or all of manual invocation sequencing code is replaced with: 1) work done by the application programmer to write the producer dependency declarations; and 2) work done by the runtime to discover and build the producer graph(s) and execute the producers of that producer graph(s). Although the effort to write the runtime is relatively great, it needs only be written once in that it can be used to execute any object-oriented applications written for the runtime; in contrast, for a typical application, the effort to write the producer dependency declarations is relatively low in comparison to writing manual invocation sequencing code.

Non-dynamic producer dependencies provide for a way to specify unconditional method invocation sequencing code, and thus avoid the need for writing unconditional manual invocation sequencing code. Contingent producer dependencies provide for a way to specify conditional processing, and thus replace the need for writing conditional manual invocation sequencing code. Supporting producer dependencies that allow for a collection of producers to be returned provides for a way to specify the filling of a collection before it is passed as a parameter, and thus avoid the need for writing multiple calls in manual invocation sequencing code to fill a collection before it is passed as a parameter. Supporting subscriptions provides an environment in which a programmer need not write specific listening code for each type of object to be listened to (e.g., in a producer graph oriented programming spreadsheet, an absorbing subscription may be used to com-

pute an average of a range of cells (each cell being a producer) by having the absorbing subscription criteria identify cells within the range, and re-computing the average every time a new producer is added to the absorbing subscription; in a producer graph oriented programming spreadsheet, a sticky subscription may be used as a currency converter by having the sticky subscription criteria identify cells holding currency content and sticky subscription characteristics of sticky producer(s) to be instantiated that perform currency conversion (the producers (holding the converted amounts) created by the sticky subscriptions would then be available for display in other cells).

Operation

New Instance Commands

FIG. **15** is a flow diagram for instantiating new instances according to one embodiment of the invention. As previously described with reference to FIG. **10**, the new class module **1095** of FIG. **10** may be implemented as part of the new instance module **1098**. The flow diagram of FIG. **15** assumes such an embodiment and is performed by the new instance module **1098**; the part of the flow diagram of FIG. **15** representing the new class module **1095** is shown as the dashed block **1580**, which includes blocks **1540** and **1550**.

Responsive to a new instance command (block **1510**), control passes to block **1520**. In block **1520**, it is determined if the instance already exists. If not, control passes to block **1530**, otherwise, the instance need not be instantiated and control passes to block **1570** in which the flow diagram ends. In one embodiment that supports instance keys, block **1520** is performed by accessing the instance tracking structure **1065** of FIG. **10** for the instance key (and class key if instance keys need not be unique across classes) provided as part of the new instance command.

In block **1530**, it is determined if the class definition of the instance is already loaded. If not, control passes to block **1540**; otherwise, control passes to block **1560**. In one embodiment that supports class keys, block **1540** is performed by accessing the class tracking structure **1092** of FIG. **10** for the class key provided as part of the new instance command.

In block **1540**, the class is loaded and control passes to block **1550**. In block **1550**, the class definition would be stored according to the class key and introspected, including any producer dependency declaration statements (stored by method key within the class—see FIG. **11**D). From block **1550**, control passes to block **1560**. With reference to FIG. **10**, the following is performed in blocks **1540** and **1550**: 1) the class would be loaded from the class definitions that include business logic **1010** into the classes **1054** (this loading results in the methods and producer dependency declarations of the class being stored in the method and producer dependency declarations **1056**); 2) the class would be added to the class tracking structure **1092**; and 3) the methods would be added to the method tracking structure **1058**. Further, the output classes of the methods would be loaded.

In block **1560**, an instance of the class would be instantiated and stored according to the instance key. With reference to FIG. **10**, the instance would be instantiated into the instances **1052**; and the instance would be added to the instance tracking structure **1065**. From block **1550**, control passes to block **1570** in which the flow diagram ends. In some embodiments of the invention in which an object-relational mapping technique is used, data may be loaded from an external data source to populate the field of the instance as part of block **1560**.

In some embodiments of the invention, classes and instances may be loaded/instantiated in a manner in which the runtime with producer graph oriented programming support is not aware (e.g., in FIG. **9**A, if the runtime **915** loads/instantiates without runtime **910** being aware). In such cases, embodiments of the invention which also support the instance key being an instance of the class InstanceKey (which holds two elements: an instance key nature indicating if the key identifier is a reference to the instance or another object (such as a string), and a key identifier which can either be a reference to the instance, or another object (such as a string)), blocks **1520** and **1530** inquire whether the instance and class were instantiated/loaded in a manner in which the runtime with producer graph oriented programming support is aware. In cases where the runtime with producer graph oriented programming support is not aware of an already loaded class, the class would not be loaded, but the class would be added to the class tracking structure **1092** and the methods would be added to the method tracking structure **1058**. In cases where the runtime with producer graph oriented programming support is not aware of an already instantiated instance, the instance would not be instantiated, but the instance would be added to the instance tracking structure **1065**.

New Producer and Unoverride Commands

FIG. **16**A is a flow diagram for instantiating new producers and unoverriding producers according to one embodiment of the invention. With reference to FIG. **10**, the flows of FIG. **16**A are performed by the automated producer graph generation module **1040** and the override producer module **1045** (or, as described with reference to alternative embodiments regarding FIG. **10**, the module that handles overrides and unoverrides).

Responsive to a new producer command (block **1600**), control passes to block **1605**. In one embodiment of the invention, a new producer command may execute responsive to a variety of situations. Table 2 below identifies the various situations and parameters passed according to one embodiment of the invention.

TABLE 2

Situations	Caller Producer	Called Producer (to be created if does not already exist)	Call type	Link mode	Dependency determination producer reference
Producer of interest	N/A	Producer of interest to be created	Of interest	N/A	N/A
Non-subscription downwardly declared	Parent	Child	Non-subscription downwardly declared	Caller parent producer link mode	Dependency determination producer providing the dependency

TABLE 2-continued

Situations	Caller Producer	Called Producer (to be created if does not already exist)	Call type	Link mode	Dependency determination producer reference
Sticky subscription	Child	Parent (parent class, method, and instance key from sticky subscription characteristics for parent producer to be created; if instance key is blank, instance key of existing child caller producer)	Sticky	Called parent producer link mode from sticky subscription characteristics for parent producer to be created	Dependency determination producer providing the dependency
Override	N/A	Producer to be overridden	Overridden	N/A	N/A
Non-subscription upwardly declared	Child	Parent	Non-subscription upwardly declared	Called parent producer link mode	Dependency determination producer providing the dependency

In block **1605**, it is determined if the producer already exists. If not, control passes to block **1610**; otherwise, control passes to block **1670**. Block **1605** is performed by accessing a class, instance, and method identified (e.g., by key and/or reference) as part of the new producer command. In one embodiment that supports producer keys, block **1605** is performed by accessing the producer graph(s) structure **1060** of FIG. **10** for the producer key provided as part of the new producer command (the producer key in the called producer column of Table 2).

In block **1610**, the new instance module is called with a new instance command and control passes to block **1615**. In one embodiment of the invention, block **1610** is performed by calling the flow diagram of FIG. **15** using the instance key from the producer key in the called producer column of Table 2.

In block **1615**, the class definition of the instance of the producer is accessed and control passes to block **1620**. With reference to FIG. **10**, block **1615** is performed by using the class key from the producer key in the called producer column of Table 2 to access the appropriate one of the classes **1054** according to the class tracking structure **1092**.

In block **1620**, the method and producer dependency declaration statement of the producer is accessed and control passes to block **1623**. With reference to FIG. **10**, block **1620** is performed by using the method key from the producer key in the called producer column of Table 2 to access the appropriate one of the methods and producer dependency declarations **1056** from the class located in block **1615**.

In block **1623**, the producer execution mode is determined and control passes to block **1625**. Details of one exemplary manner in which block **1623** is performed are discussed below. In some embodiments, a default execution mode is defined as an annotation at code level. The behavior may be overridden at run time by the end user or by the client code through a producer-based configurable decision structure (e.g., the producer based configurable decision structure **1049** in FIG. **10**) on a class basis, a method basis, an instance basis, or any combination of the above. Moreover, runtime settings may be provided to enable the runtime to ignore these programming annotations or user-defined configurations by forcing execution to be performed in a predetermined execution mode, depending on the computing environment (e.g., availability of several processors on a single machine, grid availability, load of processor(s), etc.).

In block **1625**, the producer is added to the producer graph and control passes to block **1630**. With reference to the embodiment of the invention in FIG. **11**C, the first three columns are populated.

In block **1630**, for each registered subscription, the subscription filtering criteria is processed to determine if the producer matches. With reference to the embodiment of the invention in FIG. **14**A, a subscription is considered registered when it is added to the subscription log. Exemplary operations to register subscription are described later herein. Block **1630** is an optional optimization that allows for the work of scanning the instantiated producers to be divided between automated producer graph generation and producer graph execution. As such, an alternative embodiment of the invention may not perform block **1630**.

In block **1635**, the producer is linked into the producer graph(s) if called due to a dependency. From block **1635**, control passes to block **1640**. The manner of performing block **1635** depends on the situation which resulted in the new producer command being executed. For example, if the situation is that this is a producer of interest or a producer being overridden, then it was not called due to a dependency and nothing is done. In contrast, if the situation is non-subscription downwardly declared, then it was called due to a non-subscription downwardly declared dependency; and with reference to the embodiment of the invention in FIG. **11**C, the following is performed: 1) the parent producer(s) link(s) in column **1150** of the called child producer (the called producer column of table 2) is modified with a parent producer reference to the row of the parent caller producer (the caller producer column of table 2); and the dependency determination producer reference (the dependency determination producer reference column of Table 2); and; 2) the child producer(s) link(s) column **1160** of the row of the parent caller producer (the caller producer column of table 2) is modified with a child producer reference to the row of the called child producer (the called producer column of Table 2), a dependency determination producer reference (the dependency determination producer reference column of Table 2), and a link mode (set according to the link mode column of Table 2).

In contrast, if the situation is a sticky subscription, then it was called due to a trigger producer being identified; and with

reference to the embodiment of the invention in FIG. **11**C, the following is performed: 1) the parent producer(s) links(s) column **1150** of the caller child producer (the caller producer column of table 2) is modified with a parent producer reference to the row of the parent called producer (the called producer column of table 2) and the determination dependency producer reference (the dependency determination producer reference column of Table 2); and 2) the child producer(s) link(s) column **1160** of the row of the parent called producer (the called producer column of table 2) is modified with a child producer reference to the row of the caller child producer (the caller producer column of Table 2); 2) a dependency determination producer reference (the dependency determination producer reference column of Table 2), a link mode (set according to the link mode column of Table 2) and a sticky indicator set to indicate sticky. In this respect, the situation of a non-subscription upwardly declared dependency is handled in a similar fashion to sticky subscription.

In block **1640**, the producer is marked as unexecuted and control passes to block **1645**. With reference to the embodiment of the invention in FIG. **11**C, the incremental execution marking column **1180** of the appropriate row is populated with an unexecuted indication.

In block **1645**, it is determined if the producer has any dependencies and is not overridden. If so, control passes to block **1650**; otherwise, control passes to block **1665**. Block **1645** is performed by checking the producer dependency declaration accessed in block **1620** and the call type column of Table 2.

In block **1650**, for each dependency in the producer dependency declaration that is to be resolved now, the number of producers is determined and a new producer command is invoked for each. From block **1650**, control passes to block **1655**. Different embodiments of the invention determine different types of dependency at different times; the manner of performing block **1650** in one exemplary embodiment of the invention will be described later herein.

In block **1655** the producer is added to the execution start log if all its dependent producers exist and have been executed. From block **1655**, control passes to block **1660**. When, for a given producer instantiated as part of the current iteration of this flow, block **1655** is performed, then the invocation of another iteration of this flow for a dependent producer will return the execution status of the producer (see block **1660**) (e.g., with regard to the embodiment of the invention of FIG. **11**C, the status from the incremental execution marking column **1180** of the appropriate row(s)). If all the dependent producer(s) exist and the execution status of all of the dependent producers is executed, then the producer of the current iteration is added to the execution start log.

In block **1660**, the execution status of the producer is returned as a parameter.

In block **1665**, the producer is added to the execution start log and control passes to block **1660**.

In block **1670**, similar to block **1635**, the producer is linked into the producer graph(s) if called due to a dependency. From block **1670**, control passes to block **1675**. Block **1670** may be reached for a variety of reasons. For example, block **1670** may be reached because the producer was previously instantiated responsive to a producer override command, but not linked into the producer graph. As another example, block **1670** may be reached because the producer is already part of a producer graph and is being added to another (e.g., previously instantiated responsive to being a producer of interest, a progeny of a producer of interest, etc.).

In block **1675**, it is determined if the new producer flow is called due to an override, to a sticky subscription dependency, or a non-subscription upwardly declared dependency. If so, control passes to block **1680**; otherwise, control passes to block **1660**. Block **1675** is performed by checking the call type column of Table 2 to see if this is a call for an overridden producer, a sticky subscription dependency, or a non-subscription upwardly declared dependency.

In block **1680**, similar to block **1640**, the producer is marked as unexecuted and control passes to block **1665**. Block **1680** may be reached for a variety of reasons.

Responsive to a producer unoverride command (block **1690**), control passes to block **1695**. In block **1695**, the producer is marked as not overridden and control passes to block **1640**. With reference to the embodiment of the invention of FIG. **11**C, the producer output caching and override producer output indications column **1170** of the row of the producer are accessed and altered to indicate that the producer is no longer overridden. Continuing this flow, block **1640** would lead to block **1645**, and if the producer had any dependencies, to block **1650**, which would cause the producer graph under the producer to be discovered and built if it was not already. If the producer graph under the producer is already discovered and built, then the invoking of the new producer command will result in flows going from **1600**, to **1605**, to **1670**, and so on; further, the returning of the execution status of the producers of the graph under the producer in block **1660** will determine if the producer is added to the execution start log in block **1655**. However, if the producer graph under the producer is not discovered and built, then the invoking of the new producer command will result in it being discovered and build with flows going from **1600**, to **1605**, to **1610**, and so on.

FIG. **16**B is a flow diagram for block **1623** of FIG. **16**A according to one embodiment of the invention. Thus, control flows from block **1620** to block **16231** in block **1623**. In block **16231**, a runtime execution setting override is checked. Then it is determined if the runtime execution setting override is enabled at block **16233**. If it is set, then the execution mode is set according to the runtime execution setting at block **16234**. Otherwise, the producer-based configurable decision structure for execution mode selection from end user is checked in block **16235** and control passes to block **16236**. At block **16236**, it is determined if the end user has made any execution mode selection. If yes, then the execution mode is set according to the setting in the producer-based configurable decision structure at block **16237**. Otherwise, the method definition of the producer is checked for execution mode defined as an annotation at code level and the execution mode is set according to the annotation at block **16238**. From block **16238** or block **16237**, control passes to block **16239** to end the process within block **1623**.

FIG. **17** is a flow diagram for block **1650** of FIG. **16** according to one embodiment of the invention. Thus, control flows from block **1645** to block **1700** in block **1650**. In block **1700**, for each dependency in the producer dependency declaration of the producer (one for each ArgumentDependency, FieldDependency, SequencingDependency, UpwardDependency, and WeaklyConstrainedDependency), the following blocks **1705-1745** are performed. With reference to the FIGS. **10** and **11**D, the method tracking structure is accessed to determine information regarding the producer dependency. It should also be understood that blocks **1715**, **1725**, **1730**, **1740**, **1745**, and **1750** are an optimization when performed prior to execution of the producer graph.

In block **1705**, it is determined if the dependency is an argument dependency linked already due to a sticky dependency. If so, control passes to block **1710** where the flow is complete for this dependency; otherwise, control passes to block **1715**. With regard to the embodiment of the invention

show in FIG. **11**C, the sticky indicator is checked to determine if the argument ID of this dependency is subject to a sticky subscription argument dependency or an upwardly declared argument dependency.

In block **1715**, it is determined if the dependency is a contingent dependency. If so, control passes to block **1720**; otherwise, control passes to block **1725**. Block **1715** is performed by checking the producer dependency declaration of the child producer identified by the dependency to determine if it is empty (the child producer is and independent producer). With regard to FIGS. **13**A-J, this would be true for producers with dashed circled numbers (e.g., in FIG. **13**D, producer CU::IV::DELTA), but not true for the other producers (e.g., in FIG. **13**D, producer CW::IY::BETA). Thus, with reference to FIG. **13**D, block **1715** is represented by circled **1**, **4**, and **8**. Block **1715** and the flow from it through blocks **1725**-**1750** is an optimization that both avoid adding/linking the producers with dashed circled numbers to the producer graph, as well as dividing the work of executing producers between the automated producer graph generation and producer graph execution.

In block **1720**, a new producer command for the dependency determination producer is invoked and the flow ends. For example, with reference to FIG. **13**D, block **1720** causes what is represented by circled **5**, **6**, and **7**.

In block **1725**, the dependency determination producer is executed and control passes to block **1730**. For example, with reference to FIG. **13**D, block **1725** is represented by circled **11** (thus, the flow of FIG. **17** illustrated the previously described embodiment in which circled **9** and **10** of FIG. **13**D are not performed).

In block **1730**, it is determined if the dependency is a non-subscription dependency. If so, control passes to block **1750**; otherwise control passes to block **1740**. In other words, in block **1725**, the producer dependency determination code in the method of the dependency determination producer, which is part of the producer dependency declaration of the parent producer, is executed. Having executed this producer dependency declaration code, which code would identify if this dependency is a subscription dependency, the type of producer dependency of the parent producer is determined. With regard to the example in FIG. **13**D, circled **11** would result in the flow of FIG. **17** passing from block **1730** to block **1750**.

In block **1750**, the number of producers returned by the execution of the dependency determination producer in block **1725** is determined and a new producer command is invoked for each, using the arguments described in Table 2, including the dependency determination producer reference executed in **1725**. For example, with reference to FIG. **13**D, block **1750** would cause circled **12** and **13** and circled C and D.

With reference to the absorbing subscription example of FIG. **14**B, block **1725** represents circled **4**; which causes the flow to pass through block **1730** to block **1740**.

In block **1740**, the subscription is added to the subscription log, and if the subscription is absorbing, it is marked as incomplete. From block **1740**, control passes to block **1745**. With reference to the embodiment of the invention shown in FIG. **14**A, the subscription log is populated with the subscription as previously described.

In block **1745**, all of the instantiated producers are scanned to see if they match the criteria of the subscription (and thus are a trigger producer), and any matches are processed.

FIG. **18** is a flow diagram for block **1745** of FIG. **17** according to one embodiment of the invention. Thus, control flows from block **1740** to block **1800** in block **1745**. In block **1800**, for each instantiated producer, the following blocks **1810**-**1830** are performed.

In block **1810**, it is determined if the producer meets the criteria of the subscription. If so, control passes to block **1815**; otherwise, control passes to block **1830** where the flow ends for the producer currently being processed. With reference to the embodiments of the invention shown in FIGS. **11**C and **14**A, the producer graph(s) are accessed to determine whether they include producers that meet the criteria of the subscription.

The manner of processing a matching producer depends on the type of subscription being processed. With reference to block **1815**, if the subscription is of the absorbing type, control passes to block **1825**; otherwise, control passes to block **1820**. Block **1815** would be performed responsive to the type of subscription added in **1740** or **2235**.

In block **1825**, the matching producer is added to the subscription log and the producer with the absorbing subscription is linked to the matching producer. From block **1825**, control passes to block **1830**. With reference to the embodiments of the invention shown in FIGS. **11**C and **14**A-B, the following is performed: 1) the subscription criteria from the subscription criteria for trigger producers column **1410** was used in block **1810** and a matching producer was located (e.g., one of producer **1460**A-N); 2) the matching producer is added to the matching producer column **1415** at the row of the subscription; and 3) the producer with the absorbing subscription (e.g., producer **1450**) is linked to the matching producer (e.g., the one of the producers **1460**A-N) in the producer graph(s) structure of FIG. **11**C (using the dependency determination producer reference extracted from the dependency determination producer reference column **1421** of the subscription log **14**A for the given absorbing subscription.

In block **1820**, a new producer command is invoked for the parent producer to be created. From block **1820**, control passes to block **1830** where the flow diagram ends for the current produced selected in block **1800**. With reference to the embodiments of the invention shown in FIGS. **14**A and **14**C, the following is performed: 1) the subscription criteria from the subscription criteria for trigger producers column **1410** was used in block **1810** and a matching producer was located (e.g., producer **1475**); and 2) a new producer command is invoked with the parameters of table 2 set as follows: a) call type is sticky subscription; b) caller producer is the producer key of the caller child producer (e.g., producer **1475**); c) called producer is the producer key of the called parent producer to be created (e.g., producer **1480**), that producer key being formed using the parent class, instance, and method key from the sticky subscription characteristics for the parent producer to be created (FIG. **14**A, columns **1430** and **1435** and **1437** (if the instance key is empty, the instance key of caller child producer is used); and d) the link mode for the called parent producer (figured **14**A, link mode in column **1425**, and e) the dependency determination producer reference extracted from the dependency determination producer reference column **1421** of subscription log **14**A for the given sticky subscription.

FIG. **19** is a flow diagram for block **1630** of FIG. **16** according to one embodiment of the invention. Thus, control flows from block **1625** to block **1900** in block **1630**. FIG. **19** is very similar to FIG. **18**. Specifically, blocks **1910**, **1915**, **1920**, and **1930** of FIG. **19** are identical to blocks **1810**, **1815**, **1820**, and **1830**; while block **1900** and **1925** differ from blocks **1800** and **1825**. As such, only the difference will be described here.

Block **1900** indicates the flow is performed for each registered subscription, whereas block **1800** indicates the flow is performed for each instantiated producer. Thus, where the flow of FIG. **18** is centered on a single subscription and scanning all producers, the flow of FIG. **19** is centered on a single producer and scanning all subscriptions.

Block **1925** is the same as block **1825**, with the exception that the absorbing subscription is marked as incomplete. With reference to the embodiment of the invention shown in FIG. **14**A, the completed column **1420** at the appropriate row is updated to indicate incomplete.

FIG. **20** is a flow diagram for blocks **1635** and **1670** of FIG. **16** according to one embodiment of the invention. Thus, control flows from block **1605** and block **1630** to block **2005** in blocks **1635** and **1670**. In block **2005**, it is determined if this iteration of the flow diagram of FIG. **16** was invoked due to a dependency (e.g., from block **1630** (block **1920**) or **1650** (blocks **1720**, **1750** or **1745**/**1820**) of a prior iteration). If not, control passes to block **1640** or **1675** depending from where the flow was entered (from block **1630** or **1605**).

In block **2010**, it is determined if the flow was called due to a sticky subscription or non-subscription upwardly declared situation. If not, control passes to block **2015**; otherwise, control passes to block **2020**. Block **2010** is performed by checking the call type parameter from Table 2 (i.e., whether the call type is sticky subscription or non-subscription upwardly declared or not). With reference to the embodiments of the invention shown in FIGS. **18** and **19**, if the new producer command was invoked from blocks **1820** or **1920**.

In block **2020**, the current parent producer is linked to the caller child producer. With reference to the embodiments of the invention shown in FIGS. **11**C and **14**C, the called parent producer (e.g., producer **1480**) identified by the parameter from the called producer column of table 2 is linked in the producer graph(s) structure of FIG. **11**C to the caller child producer (e.g., producer **1475**) identified by the parameter from the caller producer column of table 2, using the link mode and dependency determination producer reference identified by the parameter from the link mode and dependency determination producer reference columns of Table 2. If the parent existed previously, the behavior of block **2020** mimics the behavior of an absorbing subscription dependency in the sense that a single argument can be mapped to zero or more child producers.

In block **2015**, the caller parent producer is linked to the current called child producer. With reference to the embodiment of the invention shown in FIG. **11**C, the caller parent producer identified by the parameter from the caller producer column of table 2 is linked in the producer graph(s) structure of FIG. **11**C to the called child producer identified by the parameter from the called producer column of table 2, using the dependency determination producer reference identified by the dependency determination producer reference column of Table 2. From blocks **2015** and **2020**, control passes to block **1640** or **1675** depending for where the flow was entered (from block **1605** or **1630**).

FIG. **21**A is a flow diagram for overriding producers according to one embodiment of the invention. With reference to FIG. **10**, the flow of FIG. **21**A is performed by the override producer module **1045** (or, as described with reference to alternative embodiments regarding FIG. **10**, the module that handles overrides and unoverrides).

Responsive to an override producer command (block **2110**), control passes to block **2120**. In block **2120**, a new producer command is invoked for the producer identified by the override producer command and control passes to block **2130**. Block **2120** is performed in one embodiment of the invention in case the producer to be overridden has not yet been instantiated, as well as to mark the producer as unexecuted (block **1640** or **1680**) and log it on the execution start log (block **1665**). An alternative embodiment of the invention that does not allow the overriding of a producer that is not yet instantiated would perform an additional check between blocks **1605** and **1610** to determine if this new producer command was called responsive to an override producer command, and to indicate an error if this new producer command was called responsive to an override producer command.

In block **2130**, the output in the producer output cache (and in the instance if a field) is set and the producer is marked as overridden.

FIG. **21**B is a flow diagram for overriding producer execution modes according to one embodiment of the invention. With reference to FIG. **10**, the flow of FIG. **21**B is performed by the parallelization module **1076** (or, as described with reference to alternative embodiments regarding FIG. **10**, the module that handles parallelization).

Responsive to an override execution mode command (block **2150**), control passes to block **2155**. In block **2155**, the producer execution mode setting is overridden in the producer graph structure **1060**.

FIG. **21**C is a flow diagram for overriding producer execution modes according to one embodiment of the invention. With reference to FIG. **10**, the flow of FIG. **21**C is performed by the parallelization module **1076** (or, as described with reference to alternative embodiments regarding FIG. **10**, the module that handles parallelization).

Responsive to a runtime execution mode setting override command (block **2160**), control passes to block **2165**. In block **2165**, the producer execution mode setting is overridden globally in the runtime setting structure **1048**.

FIG. **21**D is a flow diagram for overriding producer execution modes according to one embodiment of the invention. With reference to FIG. **10**, the flow of FIG. **21**D is performed by the parallelization module **1076** (or, as described with reference to alternative embodiments regarding FIG. **10**, the module that handles parallelization).

Responsive to a configurable execution mode decision structure override producer command (block **2170**), control passes to block **2175**. In block **2175**, the producer execution mode setting is overridden globally in the producer-based configurable decision structure on a class basis, a method basis, an instance basis, or a combination of any of the above.

Global Execute Commands

FIG. **22**A is a part of a flow diagram for execution of the current producer graph(s) according to one embodiment of the invention; while FIG. **22**B is another part of a flow diagram for execution of the current producer graph(s) according to one embodiment of the invention. With reference to FIG. **10**, the flow of FIG. **22** is performed by the producer graph execution module **1070**.

Responsive to a global execute command, block **2200** shows that a set of candidate producers is selected to be executed based on the producers on the execution start log and control passes to block **2205**. In one embodiment of the invention the overridden producers are marked as unexecuted and execution thereof returns their overridden result (as opposed to causing their method to be executed), the current set of candidate producers is the producers on the execution start log. While one embodiment of the invention is described above in which overridden producers are marked as unexecuted and execution thereof returns their overridden result (as opposed to causing their method to be executed), alternative embodiments may operate differently (e.g., mark overridden producers as executed and when selecting the current

set of candidate producers, the independent producers of the execution start log and the parents of overridden producers on the execution start log are selected).

In block **2205**, a subset of producers ready for execution is selected from the set of candidate producers and control passes to block **2207**. An exemplary manner of performing block **2205** is described later herein.

In block **2207**, the producers in the current set of ready producers are executed with parallelization if parallelization is enabled. An exemplary manner of performing block **2207** is described later herein. Control passes from block **2207** to block **2208** afterwards.

In block **2208**, a task is read and removed from one of the result task queues of the supported execution modes. In the current examples, the result task queues include MP_RESULT_TASK_QUEUE, MT_RESULT_TASK_QUEUE, and LOCAL_RESULT_TASK_QUEUE. From block **2208**, control passes to block **2209**.

In block **2209**, the runtime determines if post-treatment of producers has to be skipped. If benchmarking is enabled, producers may be executed locally as well as multiprocessed. Thus, post-treatment of the producers is skipped after local execution. More details of benchmarking are discussed below. Referring back to FIG. **22**A, if post-treatment has to be skipped, then control passes to block **2248** in FIG. **22**B. Otherwise, control passes to block **2210**.

In block **2210**, the producers of the current set of ready producers are sorted by type—standard producers go to block **2220** and dependency determination producers go to block **2235**. In one embodiment of the invention, block **2210** is performed by checking the return class of the producer. With reference to the FIGS. **10** and **11**D, the method tracking structure is accessed to determine if the output class of the producer is DEP, and thus this producer is a dependency determination producer.

In block **2220**, for those parents, if any, that have an absorbing subscription on any of these executed standard producers, the subscription is marked as incomplete. With reference to FIG. **14**A, the appropriate row of the completed column **1420** is set to indicate incomplete.

In block **2235**, a new producer command is executed for any discovered producers, and subscription logging and processing is performed for any subscriptions, then control passes to block **2240**. The new producer command part of block **2235** is performed in similar manner to block **1750**, while the subscription logging and processing is performed in similar manner to blocks **1740** and **1745**.

In block **2240**, add to the set of candidate producers newly added to the execution start log. From block **2240**, control passes to block **2245**. Block **2240** is performed in similar manner to block **2200**, except only producers newly added to the execution start log as a result of block **2235** are added to the set of candidate producers.

In block **2245**, the producers that were executed are marked as executed, the producer output caching (and instance caching) are updated as necessary, the producer metrics (if acquired) are updated in the producer graph structure **1060** in FIG. **10**, any parent producers of the producers that were executed are added to the current set of candidate producers, and the producers that were executed are removed from the current set of candidate and ready producers. In some embodiments, the producer metrics may be updated by reading the corresponding task metrics and the corresponding job reference. Using the job reference, the job metrics may be read from a job metrics map. Alternatively, the producer metrics may be updated by reading the task metrics and the job metrics if a job metrics map is not used. More details of the task metrics, the job metrics, and the job metrics map are discussed below. From block **2245**, control passes to block **2248**.

In block **2248**, the result task queues are checked to determine if all of them are empty. If at least one of the result task queues is not empty, then control passes back to block **2208** to continue process the result in the non-empty result task queue(s). Otherwise, if all of the result task queues are empty, then control passes to block **2250**.

In block **2250**, it is determined if the set of ready producers is empty. If not, control passes back to block **2205**; otherwise, control passes to block **2255**.

In block **2255**, it is determined in all subscriptions have been completed. If so, control passes to block **2265** where the flow diagram ends; otherwise, control passes to block **2260**. With reference to the embodiment of the invention in FIG. **14**A, the subscription type column **1405** and the complete column **1420** are scanned for any absorbing subscriptions that are not completed.

In block **2260**, the incomplete absorbing subscriptions are processed and control passes back to block **2205**. An exemplary manner of performing block **2260** is described later herein.

FIG. **23** is a flow diagram for block **2205** of FIG. **22** according to one embodiment of the invention. Thus, control flows from block **2200** to block **2305** in block **2205**. In block **2305**, for each producer in the set of candidate producers, the following blocks **2310**-**2325** are performed.

In block **2310**, it is determined if the producer has any absorbing subscription dependency that is incomplete. If so, control passes to block **2325**; otherwise, control passes to block **2315**. With reference to the embodiment of FIG. **14**A, the subscriber's producer key column **1400** and subscription type column **1405** is scanned for a matching to the current selected producer and absorbing subscription type; and if a match is found, the completed column **1420** at the appropriate row is checked to determine the status of that absorbing subscription dependency.

In block **2315**, it is determined if the producers on which the currently selected producer depends are executed. If not, control passes to block **2315**; otherwise, control passes to block **2320**. With regard to the embodiment of the invention shown in FIG. **11**C, the incremental execution markings column **1180** for the rows of the child dependencies are checked to determined the execution status of the currently selected producer's children.

In block **2320**, the currently selected candidate producer is added to the current set of ready producers and control passes to block **2325**.

In block **2325**, the flow ends for the current produced selected in block **2305**.

FIG. **24** is a flow diagram for block **2260** of FIG. **22**B according to one embodiment of the invention. Thus, control flows from block **2255** to block **2505** in block **2260**. In block **2505**, for each producer with an absorbing subscription dependency that is incomplete, the following blocks **2510**-**2525** are performed.

In block **2510**, it is determined if all matching producers have been executed. If so, control passes to block **2515**; otherwise, control passes to block **2525**. With reference to the embodiments of FIGS. **11**C and **14**A, the matching producers column **1415** at the appropriate row is access to determine the matching producers, and the incremental execution column **1180** at the appropriate rows is checked for each of the matching producers.

In block **2515**, the absorbing subscription is marked as complete and control passes to block **2520**. With reference to

the embodiments of FIG. **14**A, the complete column **1420** at the appropriate row is set to indicate complete.

In block **2520**, the producer selected in block **2505** is added to the current set of candidate producers and control passes to block **2525**.

In block **2525**, the flow ends for the producer selected in block **2505**.

FIGS. **25** and **26** are flow diagrams for block **2207** of FIG. **22** according to one embodiment of the invention. Thus, control flows from block **2205** to block **2610** in FIG. **25**. In block **2610**, instantiation of various task queues for multiprocessing, multithreading, and local execution and a job for multiprocessing is performed. An exemplary manner of performing block **2610** is described later herein. From block **2610**, control passes to block **2620**.

In block **2620**, the set of ready producers are scanned to process the producers in the set one by one. From block **2620**, control passes to block **2622**.

In block **2622**, an execution mode of a producer is read from a producer graph structure, such as the graph structure in FIG. **11**C. Then control passes to block **2625**.

In block **2625**, a task referencing the producer and the output of the producer is created. From block **2625**, control passes to block **2630**.

In block **2630**, it is determined which execution mode the producer should be executed in. In some embodiments, there are three execution modes supported, namely, multiprocessing, multithreading, and local execution. If the execution mode is determined to be local execution, control passes to block **2632**. If the execution mode is determined to be multithreading, control passes to block **2634**. If the execution mode is determined to be multiprocessing, control passes to block **2635**.

In block **2632**, the task of the producer is pushed into the execution task queue for local execution, i.e., LOCAL_EXECUTION_TASK_QUEUE. Then control passes to block **2640**.

In block **2634**, the task of the producer is pushed into the execution task queue for multithreading, i.e., MT_EXECUTION_TASK_QUEUE. Then control passes to block **2640**.

In block **2635**, the task of the producer is pushed into the execution task queue for multiprocessing, i.e., MP_EXECUTION_TASK_QUEUE. Then control passes to block **2636**. In block **2636**, it is determined whether benchmarking between distant execution and local execution is requested. If not, control passes to block **2640**. However, if benchmarking is requested, control passes to block **2637**.

In block **2637**, the task pushed into MP_EXECUTION_TASK_QUEUE is marked to skip post-execution treatment. Then a new task referencing the producer and the output of the producer is created and is pushed into the execution task queue for local execution, i.e., LOCAL_EXECUTION_TASK_QUEUE, as well in block **2638**. Then control passes to block **2639** to store in the task added to the MP_EXECUTION_TASK_QUEUE a reference to the task added to the LOCAL_EXECUTION_TASK_QUEUE for later matching. After block **2639**, control passes to block **2640**.

In block **2640**, it is determined if all producers in the set of ready producers have been scanned. If not, control passes back to block **2620** to continue scanning producers in the set of ready producers. Otherwise, control passes to block **2642** in FIG. **26**B.

In block **2642**, the runtime determines if the MT_EXECUTION_TASK_QUEUE is empty. If so, control passes to **2660**. Otherwise, control passes to block **2644**.

In block **2644**, the runtime initiates a thread pooling mechanism if not already initiated. From block **2644**, control passes to block **2650**.

In block **2650**, a separate thread is instantiated to perform multithreading on the tasks in MT_EXECUTION_TASK_QUEUE. An exemplary manner of performing block **2650** is described later herein. From block **2650**, control passes to block **2660**.

In block **2660**, multiprocessing and local execution are performed to execute the tasks in MP_EXECUTION_TASK_QUEUE_and LOCAL_EXECUTION_TASK_QUEUE. An exemplary manner of performing block **2660** is described later herein. From block **2660**, control passes to block **2670**.

In block **2670**, it is determined if the current size of MT_RESULT_TASK_QUEUE is equal to the initial size of MT_EXECUTION_TASK_QUEUE. If not, then control remains in block **2670** because multithreading has not been completed yet on all tasks in MT_EXECUTION_TASK_QUEUE. Otherwise, control passes from block **2670** to block **2690** and the process in block **2207** ends. Although multithreading, multiprocessing, and local execution are performed sequentially in the exemplary flow described above, it should be appreciated that any combination of multithreading, multiprocessing, and local execution may be performed in parallel in some alternative embodiments.

FIGS. **27**A and **27**B are flow diagrams for block **2610** of FIG. **26** according to one embodiment of the invention. Thus, control flows from block **2205** to block **2710** in FIG. **27**A. In block **2710**, it is determined if MT_RESULT_TASK_QUEUE is instantiated. If yes, then MT_RESULT_TASK_QUEUE is cleared in block **2715**. Otherwise, MT_RESULT_TASK_QUEUE is instantiated in block **2713**. Then control passes from block **2713** or block **2715** to block **2720**.

In block **2720**, it is determined if MT_EXECUTION_TASK_QUEUE is instantiated. If yes, then MT_EXECUTION_TASK_QUEUE is cleared in block **2725**. Otherwise, MT_EXECUTION_TASK_QUEUE is instantiated in block **2723**. Then control passes from block **2723** or block **2725** to block **2730**.

In block **2730**, it is determined if MP_RESULT_TASK_QUEUE is instantiated. If yes, then MP_RESULT_TASK_QUEUE is cleared in block **2735**. Otherwise, MP_RESULT_TASK_QUEUE is instantiated in block **2733**. Then control passes from block **2733** or block **2735** to block **2740**.

In block **2740**, it is determined if MP_EXECUTION_TASK_QUEUE is instantiated. If yes, then MP_EXECUTION_TASK_QUEUE is cleared in block **2745**. Otherwise, MP_EXECUTION_TASK_QUEUE is instantiated in block **2743**. Then control passes from block **2743** or block **2745** to block **2750** in FIG. **27**B.

In block **2750**, it is determined if LOCAL_RESULT_TASK_QUEUE is instantiated. If yes, then LOCAL_RESULT_TASK_QUEUE is cleared in block **2755**. Otherwise, LOCAL_RESULT_TASK_QUEUE is instantiated in block **2753**. Then control passes from block **2753** or block **2755** to block **2760**.

In block **2760**, it is determined if LOCAL_EXECUTION_TASK_QUEUE is instantiated. If yes, then LOCAL_EXECUTION_TASK_QUEUE is cleared in block **2765**. Otherwise, LOCAL_EXECUTION_TASK_QUEUE is instantiated in block **2763**. Then control passes from block **2763** or block **2765** to block **2620**.

FIG. **28**A is a flow diagram for a process to perform multithreading according to one embodiment of the invention. As

discussed above, a separate thread is instantiated in block **2650** of FIG. **26** to perform multithreading.

In block **2820**, it is determined if MT_EXECUTION_TASK_QUEUE is empty. If the MT_EXECUTION_TASK_QUEUE is empty, that is all task in MT_EXECUTION_TASK_QUEUE have been fed to a corresponding execution thread, then the process ends. Otherwise, that is, there is at least one task to be fed to an execution thread, then control passes to block **2825** to determine if there is any thread available in the pool. If there is no thread available in the pool, control remains in block **2825** until there is an available thread. When there is an available thread, control passes to block **2830**.

In block **2830**, a task is removed from MT_EXECUTION_TASK_QUEUE and the removed task is fed to the available thread. Then control passes back to block **2820** to repeat blocks **2820**, **2825**, and **2830** until all tasks have been removed from MT_EXECUTION_TASK_QUEUE. Note that the process in blocks **2820**, **2825**, and **2830** may be performed by an instantiated thread in order to avoid blocking the rest of the flow.

FIG. **28**B is a flow diagram illustrating the execution of a task within a thread along with optional metrics acquisition. If instrumentation is requested, then the runtime starts measuring task execution time in block **2810**. Otherwise, block **2810** is skipped. From block **2810**, control passes to block **2831**. In block **2831**, a task within a thread is executed by calling the method of the task with the appropriate instance and inputs. When execution of the task is done, outputs and/or the modified instance are returned from the method and the thread is terminated. From block **2831**, control passes to block **2815**. If instrumentation is requested, then the runtime ends measuring task execution time in block **2815**. Otherwise, block **2815** is skipped.

FIG. **28**C is a flow diagram for a process responsive to thread termination callback according to one embodiment of the invention. In block **2832**, a thread termination callback is received.

In block **2834**, the output of the task within the terminated thread and the metrics acquired (such as the task execution time), if any, is stored in the task executed by the terminated thread and the task with the output and the metrics acquired, if any, is pushed into MT_RESULT_TASK_QUEUE. Then control passes to block **2836**. In block **2836**, the terminated thread is marked as available in the pool of threads.

FIGS. **29**A and **29**B are flow diagrams for block **2660** of FIG. **26** according to one embodiment of the invention. Thus, control flows from block **2650** to block **2910** in FIG. **29**A. Note that blocks that are performed for instrumentation, but are not used to implement parallelization of producer execution, are illustrated with blocks having broken dashed boundaries in FIGS. **29**A and **29**B.

In block **2910**, it is checked if MP_EXECUTION_TASK_QUEUE is empty. If MP_EXECUTION_TASK_QUEUE is empty, there is no task to be multiprocessed and thus, control passes to block **2670**. Otherwise, control passes to block **2915**.

In block **2915**, a job is instantiated and a job identifier (ID) is allocated to the job. Furthermore, a TASKS_LOCAL_MAP is instantiated in block **2915** as well. Then control passes to block **2918**. If instrumentation is requested, block **2918** is performed to start measuring job overall time. Otherwise, block **2918** is skipped. Then control passes to block **2920**.

In block **2920**, a task is read and removed from MP_EXECUTION_TASK_QUEUE. Control then passes to block **2921**. If instrumentation is requested, block **2921** is performed to start measuring task overall time. Otherwise, block **2921** is skipped. Then control passes to block **2923**.

In block **2923**, a unique task identifier (ID) is allocated to the task and stored with the task reference in TASKS_LOCAL_MAP. Then control passes to block **2925** to instantiate a task serialized form and fill the task serialized form with the task ID, a class name, and a method name of the producer corresponding to the task. Then control passes to block **2930**.

In block **2930**, a serialized form of each one of all input producers and the underlying instance is found if already created. Alternatively, if a serialized form is not yet created, it is created in block **2930**. Exemplary manner to perform block **2930** is discussed herein. From block **2930**, control passes to block **2960**.

In block **2960**, the task serialized form is added to a serialized task execution queue of the job, namely, JOB.SERIALIZED_TASKS_EXECUTION_QUEUE. Then control passes to block **2965**.

In block **2965**, it is determined if MP_EXECUTION_TASK_QUEUE is empty. If MP_EXECUTION_TASK_QUEUE is not empty, control passes back to block **2920** to continue going through the remaining tasks in MP_EXECUTION_TASK_QUEUE. Otherwise, control passes to block **2970**.

In block **2970**, the job is sent to a grid of a number of distant processors. The grid of processors performs distant computing to execute the job. Details of one exemplary flow of distant computing are discussed herein. Then control passes to block **2972** to perform local execution. From block **2972**, control passes to block **2973**.

In block **2973**, it is determined if the job is done. If not, control remains in block **2973** until the job is done. When the job is done, control passes to block **2975** in FIG. **29**B.

Referring to FIG. **29**B, a job virtual local processing time is set to zero in block **2975**. According to one aspect of the invention, the job virtual local processing time is the time would have taken all the tasks of the job to be executed locally. From block **2975**, control is passed to block **2977**.

In block **2977**, a task is read and removed from the serialized result queue of the job, i.e., JOB.SERIALIZED_TASKS_RESULTS_QUEUE. Then control is passed to block **2979** to find the task reference using the task ID stored in the TASKS_LOCAL_MAP. Then control passes to block **2980**.

If instrumentation is requested, block **2980** is performed to determine the output serialized form size and to start measuring local deserialization time of the output. Otherwise, block **2980** is skipped and control passes to block **2981**. In block **2981**, the output in the task output is deserialized. From block **2981**, control passes to block **2982**. Again, if instrumentation is requested, block **2982** is performed to end measuring local deserialization time. Further, if instrumentation is requested, blocks **2984**, **2985**, **2987**, and **2989** may be performed. Otherwise, blocks **2984**, **2985**, **2987**, and **2989** are skipped and control passes from block **2981** to block **2990**.

In block **2984**, the runtime ends measuring task overall time and then removes local execution time from the task overall time. From block **2984**, control passes to block **2985**.

In block **2985**, it is determined whether benchmarking is requested. If benchmarking is requested, control passes to block **2987** and then to block **2989**. Otherwise, control passes to **2989** from **2985** to skip block **2987**.

As discussed above with reference to FIGS. **25** and **26**, benchmarking is requested to compare local and distant execution times. Thus, a task is executed both locally and distantly using multiprocessing if benchmarking is requested according to one embodiment of the invention. Thus, if

benchmarking is requested, the runtime may find a corresponding task in LOCAL_RESULT_TASK_QUEUE in block **2987**. Further, the runtime may add the local processing time stored in the task to the job virtual local processing time. As such, the job virtual local processing time equals to the sum of the local processing times of all tasks in the job when all tasks have been executed. From block **2987**, control passes to block **2989**.

In block **2989**, the task metrics, such as task overall time, along with the job ID are added to the task. Then control passes to block **2990**. Note that both blocks **2987** and **2989** are performed if instrumentation is requested. Otherwise, both blocks **2987** and **2989** may be skipped.

In block **2990**, the task is pushed in MP_RESULT_TASK_QUEUE. Then control passes to block **2991**. In block **2991**, it is determined if JOB.SERIALIZED_TASKS_RESULTS_QUEUE is empty. If not, then control passes back to block **2977** to continue reading tasks from the queue and deserializing the outputs. Otherwise, control passes to block **2992** if instrumentation is requested. If instrumentation is not requested, then control passes from block **2991** to block **2670** in FIG. **26**B.

If instrumentation is requested, blocks **2992**, **2993**, **2995**, **2996**, and **2997** may be performed. Otherwise, blocks **2992**, **2993**, **2995**, **2996**, and **2997** may be skipped. In block **2992**, the measuring of job overall time is ended and then local execution time is removed from the job overall time. From block **2992**, control passes to block **2993**.

In block **2993**, it is determined if benchmarking is requested. If benchmarking is requested, control passes to block **2995**. In block **2995**, the job speedup is computed by dividing the job virtual local processing time with the job overall time. Then control passes from block **2995** to block **2996**. In block **2996**, job efficiency is computed by dividing the job speedup with the number of processors available and dedicated to the execution of the job in the grid. From block **2996**, control passes to block **2997**. Otherwise, if benchmarking is not requested, control passes from block **2993** to block **2997** directly.

In block **2997**, the metrics of the job (e.g., job speedup, job efficiency, job overall time, etc.) are added to each task within the job. From block **2997**, control passes to block **2670** in FIG. **26**B.

FIG. **30** shows a flow diagram for block **2930** of FIG. **29**A according to one embodiment of the invention. Thus, control flows from block **2925** to block **3010** in FIG. **30**. In block **3010**, it is determined if a serialized form of an input producer or of the underlying instance is already created in the SERIALIZED_FORM_LOCAL_MAP based on the input producer key or the underlying instance key. If the serialized form is already created, control passes to block **3015**. Otherwise, control passes to block **3020**.

In block **3015**, the serialized form ID and the serialized form are read from the SERIALIZED_FORM_LOCAL_MAP. Then control passes to block **3040**.

In block **3020**, a serialized form identifier is allocated to the input producer or the underlying instance. Then control passes to block **3022**.

In block **3022**, the measurement of local serialization time is started. Then control passes to block **3024**.

In block **3024**, a serialized form is created for the input producer or the underlying instance. Then control passes to block **3026**.

In block **3026**, the measurement of local serialization time is ended. Then control passes to block **3028**.

In block **3028**, the input serialized form size is determined. Then control passes to block **3030**.

In block **3030**, the input producer key or the underlying instance key, the serialized form ID, and the serialized form are stored in the SERIALIZED_FORM_LOCAL_MAP. The SERIALIZED_FORM_LOCAL_MAP may be global or allocated and freed on a job by job basis, depending on various factors, such as memory requirements, performance requirements, etc. Then control passes to block **3034**.

In block **3034**, the input serialized form size and the serialization time are stored with the serialized form ID in the SERIALIZED_FORM_LOCAL_MAP. Then control passes to block **3040**. Note that blocks **3022**, **3026**, **3028**, and **3034** described above are performed if instrumentation is requested. Blocks **3022**, **3026**, **3028**, and **3034** may be skipped if instrumentation is not requested.

In block **3040**, it is determined if the serialized form ID is in the JOB.SERIALIZED_FORM_MAP. If yes, then control passes to block **3045**. Otherwise, control passes to block **3043**.

In block **3043**, the serialized form ID and the serialized form are stored in JOB.SERIALIZED_FORMS_MAP. Then control passes to block **3045**.

In block **3045**, the serialized form ID is added as an input or as an underlying instance to the task serialized form. From block **3045**, control passes to block **3050**.

In block **3050**, it is determined if there is any more input producer not yet processed or if the underlying instance is not yet processed. If there is, then control passes back to block **3010**. Otherwise, control passes to block **2960** in FIG. **29**A.

FIGS. **31**A and **31**B show flow diagrams of distant computing for multiprocessing according to one embodiment of the invention. Again, blocks illustrated with broken dash line are performed if instrumentation is requested and may be skipped if instrumentation is not requested. As discussed above, a job including a number of tasks corresponding to producers is dispatched to a grid of processors for execution. Each processor in the grid, also referred to as a worker, may cache the JOB_SERIALIZED FORMS_MAP. For example, if a job holds a thousand tasks and there are ten workers executing these tasks, the JOB_SERIALIZED FORMS_MAP is sent once by the grid dispatcher to each worker, and cached at worker level. When the job is finished, the grid dispatcher sends a command to the worker in order to free up the cache. The flow starts at block **3108**.

In block **3108**, the JOB_SERIALIZED_FORMS_MAP along with the task serialized form holding input IDs, class name, and method name are received from the grid dispatcher. Then control passes to block **3110**. In block **3110**, a class is located using the class name and a method is located using the method name. The class and the method are loaded to reconstitute a task. Then control passes to block **3112**.

In block **3112**, a task input ID or the instance ID is looked up from the JOB.SERIALIZED_FORMS_MAP. Then control passes to block **3120**.

In block **3120**, it is determined if the input ID is found. If not, control passes to block **3190** to return an error. Otherwise, control passes to block **3130**.

In block **3130**, it is determined if the JOB.SERIALIZED_FORMS_MAP entry corresponding to the input ID is already deserialized. If it is already deserialized, then control passes to block **3150**. Otherwise, control passes to block **3132**.

In block **3150**, the deserialized form of the input is extracted. Then control passes to block **3155**.

In block **3132**, the measurement of distant deserialization time is started. Then control passes to block **3134** to deserialize the JOB.SERIALIZED_FORMS_MAP entry corresponding to the input ID. From block **3134**, control passes to

block **3136**. In block **3136**, the measurement of distant deserialization time is ended. Then control passes to block **3138**.

In block **3138**, the corresponding entry in the JOB.SERIALIZED_FORMS_MAP is enriched with the deserialized form. Then control passes to block **3143**.

In block **3143**, the instance or the standard input is added to the task definition. Then control passes to block **3155**.

In block **3155**, it is determined if all input IDs (i.e., all standard inputs along with the underlying instance) have been processed. In other words, it is determined if the task has been completely reconstituted or deserialized. If so, control passes to block **3160** in FIG. **31**B. Otherwise, control passes back to block **3112** to process the next input ID.

Referring to FIG. **31**B, the measurement of distant processing time is started in block **3160**. Then control passes to block **3162**.

In block **3162**, the method with the appropriate instance and inputs is called. As a consequence of the execution, the method may return an output and/or modify the instance of the method. The runtime receives the output returned from the method and/or the modified instance. Then control passes from block **3162** to block **3166**.

In block **3166**, the measurement of distant processing time is ended. Then control passes to block **3170**.

In block **3170**, the measurement of distant serialization time is started. Then control passes to block **3172** to serialize the returned output and/or the modified instance and attach the serialized output and/or the serialized modified instance to the task. Then control passes to block **3174**. In block **3174**, the measurement of distant serialization time is ended. From block **3174**, control passes to block **3176**.

In block **3176**, the metrics (e.g., distant serialization time, distant deserialization time, etc.) are stored in the task. Then control passes to block **3180**.

In block **3180**, the task is sent back to the grid dispatcher of the runtime and the flow ends. Again, blocks illustrated with broken dash line are performed if instrumentation is requested and may be skipped if instrumentation is not requested.

FIG. **32** shows a flow diagram for block **2972** of FIG. **29**A according to one embodiment of the invention. Thus, control flows from block **2970** to block **3202** in FIG. **32**. Again, blocks illustrated with broken dash line are performed if instrumentation is requested and may be skipped if instrumentation is not requested.

In block **3202**, the measurement of local execution time is started. Then control passes to block **3210**.

In block **3210**, a task is removed from LOCAL_EXECUTION_TASK_QUEUE and is executed locally by calling the method with the appropriate instance and inputs. When execution is done, the method returns outputs and/or the modified instance of the method. Then control passes to block **3212**.

In block **3212**, the measurement of local execution time is ended. Then control passes to block **3220**.

In block **3220**, the output of the task is stored in the task. Then control passes to block **3223**.

In block **3223**, the metrics (e.g., local execution time) is stored in the task as well. Then control passes to block **3230**.

In block **3230**, the task is pushed into the LOCAL_RESULT_TASK_QUEUE. From block **3230**, control passes to block **3240**.

In block **3240**, it is determined if the LOCAL_EXECUTION_TASK_QUEUE is empty. If the queue is empty, then control passes to block **2973** in FIG. **29**A. Otherwise, control passes back to block **3202** to repeat the process to execute another task locally.

Alternative Embodiments

While the flow diagrams in the figures show a particular order of operations performed by certain embodiments of the invention, it should be understood that such order is exemplary (e.g., alternative embodiments may perform the operations in a different order, combine certain operations, overlap certain operations, etc.)

While the invention has been described in terms of several embodiments, those skilled in the art will recognize that the invention is not limited to the embodiments described, can be practiced with modification and alteration within the spirit and scope of the appended claims. The description is thus to be regarded as illustrative instead of limiting.

What is claimed is:

1. A computer implemented method comprising:

receiving a request to run an application program, wherein object-oriented code of the application program includes methods and producer dependency declarations, wherein a producer is an instance of a class and a specific method of that class, wherein each of the producer dependency declarations is for one of the specific methods and is to identify at run time a set of zero or more producers; and

parallelizing execution of the application program based on dependencies between producers of the application program using the runtime, wherein execution of each of the producers requires outputs of all of the set of producers identified by the producer dependency declaration for the specific method of that producer be available before the runtime begins executing the specific method of that producer.

2. The method of claim **1**, wherein parallelizing execution of the application program comprises:

identifying a set of ready producers among the producers of the application program;

determining an execution mode of each producer of the set of ready producers; and

causing each producer of the set of ready producers to be executed in a corresponding execution mode.

3. The method of claim **2**, wherein the execution mode is one of a local execution mode, a multiprocessing mode, and a multithreading mode.

4. The method of claim **2**, wherein determining the execution mode of each producer of the set of ready producers comprises:

checking an execution mode setting of a method of a corresponding producer; and

overriding the execution mode setting of the corresponding producer if an end user selects another execution mode on at least one of a class basis, a method basis, and an instance basis.

5. The method of claim **1**, further comprising:

acquiring metrics related to the execution of the application program using the runtime on a producer by producer basis in response to an instrumentation request, comprising,

measuring execution time of the application program on a producer by producer basis.

6. The method of claim **5**, wherein acquiring metrics further comprises:

measuring execution time of the application program on a job basis, wherein a job comprises a plurality of producers to be multiprocessed.

7. An apparatus comprising:

a computer with a runtime to run object-oriented code with producer dependency declarations for specific methods and execution mode settings for those methods, wherein

a producer is an instance of a class and a specific method of that class, wherein each producer dependency declaration is for one of the specific methods and is to identify at run time a set of zero or more producers, wherein execution of each producer requires outputs of all of the set of producers identified by the producer dependency declaration for the specific method of that producer be available before the runtime begins executing the specific method of that producer, and

wherein said runtime includes,

an automated producer graph execution module to execute a plurality of producers to determine an output of a producer of interest, wherein the automated producer graph execution module comprises,

a parallelization module to cause zero or more of the plurality of producers to be executed in parallel.

8. The apparatus of claim **7**, wherein the automated producer graph execution module further comprises:

a local execution module coupled to the parallelization module to cause a producer having an execution mode of local execution to be executed locally.

9. The apparatus of claim **8**, wherein the automated producer graph execution module further comprises a metrics acquisition module to measure local execution time of the producer having the execution mode of local execution if instrumentation is requested.

10. The apparatus of claim **7**, wherein the automated producer graph execution module further comprises:

a multithreading module coupled to the parallelization module to initiate a thread pooling mechanism and to feed available threads with multithreading tasks corresponding to producers having an execution mode of multithreading.

11. The apparatus of claim **10**, wherein the automated producer graph execution module further comprises a metrics acquisition module to measure execution time of each of the producers having the execution mode of multithreading if instrumentation is requested.

12. The apparatus of claim **7**, wherein the automated producer graph execution module further comprises:

a multiprocessing module coupled to the parallelization module to instantiate a job, to serialize multiprocessing tasks corresponding to producers having an execution mode of multiprocessing, to serialize inputs and underlying instances of the multiprocessing tasks, to add the serialized multiprocessing tasks and the serialized inputs and the serialized underlying instances to the job, and to provide the job to a grid dispatcher, the grid dispatcher to dispatch the job to a grid having a plurality of processors to execute the multiprocessing tasks in the job.

13. The apparatus of claim **12**, wherein the automated producer graph execution module further comprises a metrics acquisition module is to measure execution time of each of the multiprocessing tasks corresponding to the producers having the execution mode of multiprocessing, serialization time and size of the multiprocessing task inputs, outputs, and instances within the job, deserialization time and size of the multiprocessing task inputs, outputs, and instances within the job, and execution time of the multiprocessing tasks within the job if instrumentation is requested.

14. The apparatus of claim **7**, wherein the runtime further comprises:

a producer-based configurable decision structure coupled to the parallelization module to store execution mode based on a combination of one or more of a class key, an instance key, and a method key from a runtime client; and

an automated producer graph generation module operable to determine the execution mode based on the execution mode selections, the execution mode settings, and a runtime override setting, if any.

15. The apparatus of claim **7**, wherein the runtime further comprises:

a producer graph structure coupled to the automated producer graph execution module to store outputs of the plurality of producers, the execution mode settings, and metrics acquired, if any.

16. A non-transitory machine-readable storage medium that provides:

an application program, object-oriented code of the application program including:

a plurality of class definitions each including,

a set of one or more fields,

a set of one or more methods,

a producer dependency declaration for each method of said set of methods, wherein the producer dependency declaration for a given one of said methods is used by a runtime to identify at run time a set of zero or more producers that are to be executed substantially in parallel, and wherein a producer is an instance of one of the plurality of classes at run time and a method of that class wherein execution of each producer requires outputs

of all of the set of producers identified by the producer dependency declaration for the method of that producer be available before the runtime begins executing the method of that producer.

17. The machine-readable medium of claim **16**, wherein the object-oriented code further includes:

an execution mode setting for each method of said sets of methods.

18. The machine-readable medium of claim **17**, wherein the execution mode is one of a local execution mode, a multiprocessing mode, and a multithreading mode.

19. The machine-readable medium of claim **17**, wherein one or more of the plurality of class definitions further include:

one or more execution mode settings provided in annotation.

20. The machine-readable medium of claim **16**, wherein the object-oriented code further includes:

an override runtime execution mode setting command to override the execution mode at runtime level.

21. The machine-readable medium of claim **16**, wherein the object-oriented code further includes:

a configurable decision tree execution mode setting command to override the execution mode on a basis of at least one of a class, a method, and an instance.

22. The machine-readable medium of claim **16**, wherein the runtime is operable to automatically generate and execute a producer graph for a designate producer of interest through instantiation, as necessary, and linking of other producers based on the producer dependency declarations of the methods of the producer and interest and the other producers, wherein the runtime is operate to execute at least two of the producers in the producer graph in parallel based on dependencies between the producers as indicate in the producer graph.

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